Cunninghamia
A journal of plant ecology for eastern Australia

Date of Publication:
March 2016

The Royal
Botanic Garden
Sydney

ISSN 0727-9620 (print) • ISSN 2200-405X (Online)

Dieback of *Nematolepis ovatifolia* (Rutaceae), an endemic shrub in the alpine- subalpine heaths of the Snowy Mountains, is facilitated by climate change.

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Abstract: The shrub *Nematolepis ovatifolia* (F. Muell.) Paul G. Wilson (family Rutaceae) is endemic to the alpine and subalpine areas of the Snowy Mountains, Australia, where it dominates large areas of heath. Mass dieback was observed in the spring/summer of 2012. Damage at first was confined to the tips of branches, a symptom that could be due to frost damage and/or pathogen-induced water stress. Subsequently, whole stems and shrubs died and new areas of chlorosis appeared on smaller shrubs. Surveys of 186 sites covering the geographical range of the shrub in the summers of 2013/14 and 2014/15 found that 59 populations were definitely dieback affected, 92 had early symptoms and 35 were healthy. Two possible causes were investigated: killing frost and pathogens, with insect attack being a further cause of defoliation.

The root rot pathogen, *Phytophthora cambivora* was isolated from one washed root sample and from one of five soil/root samples. In 2014/15, in five sites where symptomatic plants were monitored, most plants recovered to a condition where they were considered unaffected in March 2015. It is possible that symptomatic plants had in fact suffered frost damage. Hence populations with early symptoms were grouped with healthy populations for analysis of proximity to trails. Compared with these, dieback affected populations were significantly closer to trails. It could not be determined when the pathogen was introduced, as it could have been imported on earthmoving equipment or by subsequent users of trails. It was apparently well spread before spring of 2012 but infection of plants was not evident. Its sudden eruption in spring of 2012 may have been facilitated by two warm and wet La Nina years, with mean growing season soil temperature up to 1.5°C higher than the long term mean and growing season rainfall double the long term mean. Plant death occurred in the hottest year on record in Australia, with the average alpine treeline growing season soil temperature of 9.2°C in 2012/13 being >2.0°C above the long term mean.

Cunninghamia (2016) 16: 1–9
doi:10.7751/cunninghamia.2016.16.001

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Introduction

Shrubs and grasslands alternate in cycles throughout the Australian Alps, with senescence of shrubs and colonization by grasses being recorded from the alpine zone in the Snowy Mountains (Costin 1959) and in the subalpine zone in the Victorian Alps (Williams and Ashton1988). Generally large-scale shrub death in mountain areas is uncommon apart from large-scale senescence where shrubs are of a similar age after mass recruitment post-fire or in the aftermath of removal of grazing (Clarke *et al.* 2015). The most commonly recorded dieback in high mountains in Australia is insect related, for example defoliation of large areas of alpine grasslands in the Snowy Mountains by swiftmoths (Green & Osborne 2012). There have been few incidences reported from overseas, with more attention being focused on large areas of subalpine forests being killed by beetles, (*Dendroctonus* spp.) and their microbial associates with the elevational range of infestation increasing into the alpine treeline ecotone (Raffa *et al.* 2012; Donato 2013). Substantial dieback of native shrubs occurred in Barrington Tops in northern New South Wales due to an exotic pathogen, the soil-borne water mould *Phytophthora cinnamomi* (McDougall *et al.* 2003). Previously *Phytophthora cinnamomi* in the area had only been found at elevations below 800 m; its presence at 1560 m elevation was a cause of considerable concern for National Park management (NPWS 2015).

Causes of large-scale shrub death are not only biotic. Frosts have resulted in extensive damage to shrubs in the Snowy Mountains, particularly in years with shallow snow cover combined with very low minimum temperatures. At Kiandra in 1982 overnight temperatures fell to below –10 °C on eight nights with the coldest being –21.5°C. The shrub *Bossiaea foliosa* was killed and the cover of tall shrubs was reduced by 32% with no resprouting (Leigh *et al.* 1987). In the same year, at higher elevations where plants were usually afforded some protection from mid-winter frosts by snow cover, the frosts accompanied the shallowest recorded snow to that date in the Snowy Mountains with widespread damage to vegetation. Shrub genera including *Nematolepis*, *Tasmannia* and *Podocarpus* were affected and also the tree *Eucalyptus niphophila* (Green & Osborne 1994). Leigh *et al.* (1987) suggested that a frost as harmful as the one in 1982 would be a one in 50 year event. In summer of 2012-2013 another mass die off of shrubs was recorded, this time mainly affecting a single species.

Ovate Phebalium, *Nematolepis ovatifolia* (F.Muell.) Paul G.Wilson (previously *Phebalium ovatifolium*) (family Rutaceae) is a Snowy Mountains endemic shrub (Doherty *et al.* 2015), one of 21 species endemic to this region (Costin *et al.* 2000). Mass dieback in *Nematolepis ovatifolia* across the Snowy Mountains appeared in the spring of 2012. The damage, at first, was confined to tips of branches of taller shrubs. This resembled damage noted in spring 1982 (see Green & Osborne 2012-page 48). However, as summer 2012/13 progressed, whole stems and shrubs subsequently died and new areas of chlorosis appeared on both smaller shrubs and previously unaffected tall shrubs, with large areas of the shrub becoming chlorotic and then turning a chestnut brown before dying (Fig. 1). In spring/summer 2013/14 there was a recurrence of the dieback with the early symptoms, those confined to the tips of branches, appearing across the entire geographical range of *Nematolepis ovatifolia* in the central portion of Kosciuszko National Park.

At first, damage was confined to the tips of branches suggested that killing frost could explain the die off. However, as the damage spread from the tips of branches to engulf whole shrubs, pathogens were also suspected. At the same time, shrubs over large areas in the north of Kosciuszko National Park were being defoliated and dying from insect attack (McDougall *et al.* 2015). To determine the cause of the *Nematolepis* dieback, three possible agents were investigated: killing frost, pathogens and insect attack. To assess the extent and possible causes of the dieback of *Nematolepis ovatifolia* data were collected on (1) the geographic extent and condition of populations of *Nematolepis ovatifolia*, (2) climatic conditions in the alpine/subalpine area including frosts, (3) soil pathogens and treatment, and (4) insect damage.

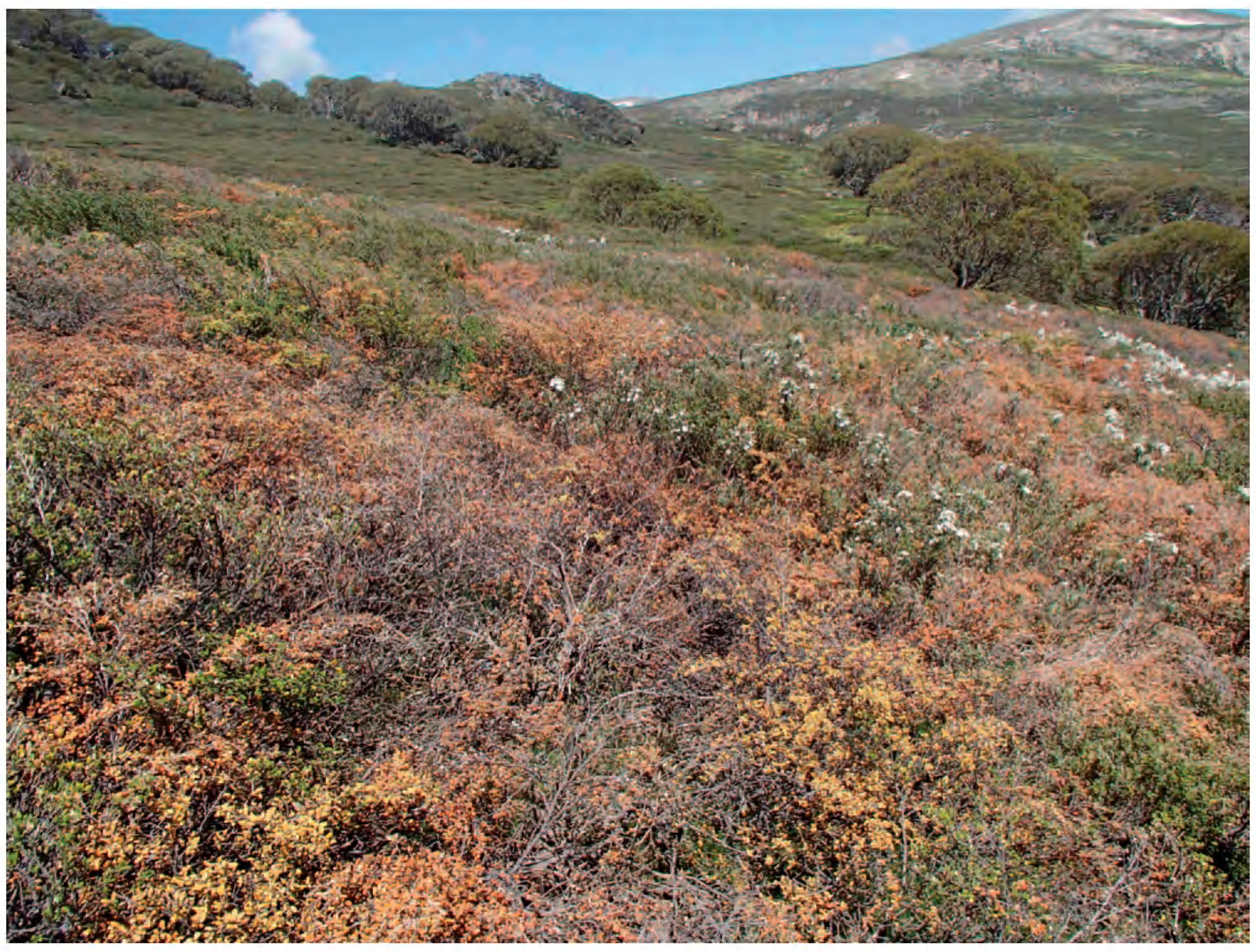

Figure 1. Part of a patch of *Nematolepis ovatifolia* at the alpine treeline in summer 2012/13 where 676 mainly mature shrubs suffered from dieback, showing the stages of infection from normal green to chlorotic, yellow, brown and defoliated.

Methods

Geographic extent of Nematolepis ovatifolia

The geographic range of *Nematolepis ovatifolia* was initially obtained from online records from the Australian National Herbarium (2015), the collection of the National Herbarium of New South Wales (2015) and the Office of Environment and Heritage Atlas of NSW Wildlife (2015), together with specimen vouchers from the Kosciuszko National Park Herbarium. This was then followed up by a field survey aimed to encompass the entire range of *Nematolepis ovatifolia* based on these herbarium records as the core distribution (Fig. 2). The range of *Nematolepis ovatifolia* was traversed in summer 2013/14 and 2014/15 and populations were assessed as affected (chlorosis or death of leaves over entire branches), symptomatic (chlorosis or death of leaves at the tips of branches) and unaffected. The search for the limits of populations of *Nematolepis ovatifolia* included a vehicle traverse of all adjacent fire-trails to the west and along the northern boundary with the eastern distribution undertaken on foot as was the high level western distribution and the area south of the Thredbo River (Fig. 2). Population locations were recorded on a hand-held Global Positioning System (GPS) unit, and the distance to the nearest fire trail, access track or road for each population was calculated in Arc GIS (Esri ArcMap 10.1). To determine if affected populations were closer to trails or roads, the distances to trails (log transformed) were compared between affected populations and symptomatic/unaffected populations using a Student's t test. Other environmental factors recorded included position on slope and presence of other dead or dying plant species.

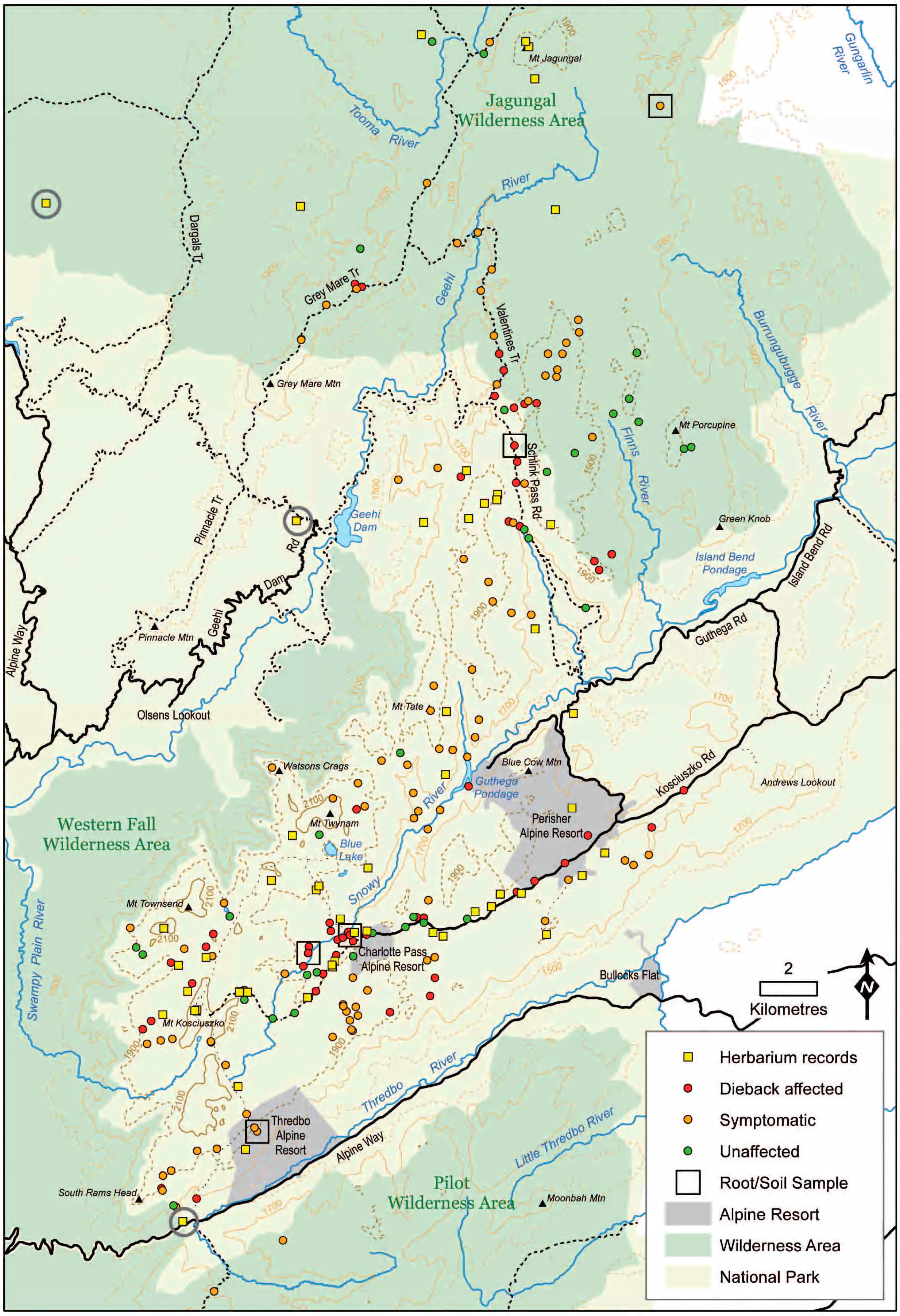

Figure 2. Map of the extent of *Nematolepis ovatifolia* from online herbarium records (three erroneous records circled) and 186 locations assessed either as unaffected, those with apparent early symptoms of dieback, and those seriously affected by dieback in the summers of 2013/14 and 2014/15. Locations where populations were sampled for *Phytophthora cambivora* are boxed. *Phytophthora* was actually confirmed through baiting results at the sites at Charlotte Pass and Thredbo.

Climatic and microclimatic data

To examine the thermal conditions in both air and soil in the period up to and including the death of plants, temperature data were collected from a number of loggers used in other studies. Air temperature data came from a Tinytag Plus temperature logger (Gemini Data Loggers, Chichester, England) recording at 60-minute intervals that was located in the Stevenson meteorological screen at Charlotte Pass. Soil temperature data were obtained from identical loggers at 10 cm depth in the soil at the alpine treeline ecotone on the lower slopes of Mt. Clarke, a permanently monitored site and a part of the international GLORIA network (A Global Observation Research Initiative in Alpine Environments).

To examine the potential exposure of plants to thermal conditions not buffered by snow cover, snow depth data were collected from long-term snow measuring sites associated with hydrological or vegetation monitoring. Snowpack depth data came from the Snowy Hydro snowcourse located at Spencers Creek and the Kostex site (Kosciuszko treeline experiment), where seedlings of *Eucalyptus niphophila* had been planted above the alpine treeline in March 2007.

To determine the potential for plants to project above the snow, plant heights were measured across a range of affected and unaffected populations of *Nematolepis ovatifolia* at elevations from 1720 m to 2020 m. In each population, shrubs were selected by throwing a pole into the population and measuring the height of the nearest 30 individuals.

Pathogens

To assess if plant pathogens were causing the dieback of *Nematolepis ovatifolia,* soil and root samples were collected and analysed. One lesioned root sample from a dying *Nematolepis ovatifolia* shrub exhibiting dieback symptoms was collected below Charlotte Pass in December 2012 and sent for testing to the Plant Disease Diagnostic Unit at the Royal Botanic Gardens Sydney and subsequently material was forwarded to the Centre of Phytophthora Science and Management diagnostic laboratory at Murdoch University for molecular confirmation of the identity of the pathogen. For confirmation of *Phytophthora cambivora* from baiting results, five more root samples with attached soil were collected from symptomatic plants throughout the range of the species in 2013 (Fig. 2), with a further 20 soil samples collected in 2014 (not shown). The five soil/root samples taken in 2013 were sent to Murdoch University for analysis and the 20 soil samples taken in 2014 were sent to the Royal Botanic Gardens Sydney.

Monitoring sites

At four populations along the Kosciuszko Road across four elevations 30 plants were monitored per elevation in one of a number of preliminary trials of a phosphite-based systemic fungicide (Aus-Phoz 600, Australian Agricultural Chemicals). Because nothing is known about side effects or toxicity of phosphite in Australian alpine vegetation and wetting agents might also be phytotoxic (Hardy *et al.* 2001) a precautionary approach was taken and phosphite and wetting agents were tested separately. In paired field trials, two shrubs of similar size and with similar symptoms in close proximity were randomly allocated to either treatment or control. 60 symptomatic shrubs were sprayed with 0.5% phosphite, with the paired nearby shrub being sprayed with tap water from a separate, clean spraypack. Shrubs were marked with flagging tape and each shrub photographed to record the symptoms. At the end of February 2015 the shrubs were resurveyed and the status of the plants recorded.

Plants with extensive damage were not used in the phosphite trial. To monitor seriously affected plants a population of *Nematolepis ovatifolia* at Whites River just west of the Schlinks Pass Road was assessed (Fig. 2). The site had 75 permanently marked points where vegetation regrowth was monitored annually from the fires of 2003. In December 2014 each site that contained *Nematolepis ovatifolia* was assessed for condition as above and re-assessed in March 2015.

Insect damage

Plants were searched for any evidence of insects, either larvae or silk. Shrubs known to be attacked by insects, mainly Asteraceae family were also investigated during the survey of the geographic range of *Nematolepis ovatifolia.*

Results

Geographic extent

The survey in the summers of 2013/14 and 2014/15 found *Nematolepis ovatifolia* at elevations from 1610 to 2140 metres. There were four erroneous herbarium records lower than this, one in Victoria and three circled in Figure 2. One was listed as "Thredbo Village" but could have been at the top of the chairlift rather than the bottom (a 575 m difference in elevation) because *Nematolepis ovatifolia* does not occur in the valley around Thredbo Village (pers. obs; Euan Diver pers. comm.). A second site marked just off the Geehi Dam Road actually gives a written description of "Windy Creek" which is the sampling site of the marked location due east of this, so it appears that the longitude was incorrectly entered on the voucher label. The third site is at low elevation to the north-west in rainforest conditions on the steep slopes falling away from the Dargals Trail and is likely to be wrong.

Of the 186 sites surveyed across the range limit of *Nematolepis ovatifolia* in 2013/14 and 2014/15, 59 populations were definitely affected, 92 were symptomatic and 35 were considered healthy (Fig. 2). There were 12 other plant species with death recorded, but only two of these were found dead in more than 10 sites: the shrubs *Orites lancifolia* (14 sites) and *Grevillea australis* (32 sites). Areas of affected plants commonly spread downhill from trails and along water courses.

Following heavy and continued rains through January 2015, some sites were re-assessed. Newly affected shrubs were only seen in locations such as Charlotte Pass where a high number of plants had already died. Elsewhere, apparent recovery had occurred in populations originally classified as having symptoms. Twigs that had previously held chlorotic or browned leaves had shed these leaves and other twigs or branches did not exhibit new symptoms. It appears that the populations with affected shrubs were correctly categorized as such, but some of those with suspicious symptoms in the 2013/14 survey would be considered unaffected in 2015. Hence for analysis the populations categorized as symptomatic and unaffected were combined into one group and the distance to the nearest trail was compared between these sites and the seriously affected sites. Affected populations were found to be significantly closer to the trails ($t = 2.65$, $df = 184$, $p < 0.01$) than unaffected populations and those with some early symptoms. The distribution of affected plants had two large centres, at Charlotte Pass and the Valentines Trail, with isolated areas radiating from there. There was overall a diminishing incidence northwards to the limit of *Nematolepis ovatifolia* just to the north-west of Mt Jagungal and also overall a diminishing incidence with elevation above the alpine treeline.

Insect damage

Lepidopteran larvae were frequently found in shelters of leaves bound together by silk at the tips of branches from shrubs of the family Asteraceae. Collections, from similar shelters at the tips of twigs of *Nematolepis ovatifolia* from the north-eastern extent of the range also found similar lepidopteran larvae at different developmental stages superficially resembling a Leaf Rolling Moth species from the family Tortricidae or Oecophoridae. (Thomas Wallenius pers. comm.). Large areas of insect defoliation of Asteraceae were commonly found during the survey of *Nematolepis ovatifolia*, however similar defoliation of *Nematolepis* was rare and confined only to just above the alpine treeline at Thredbo.

Killing frost

Snow depth at the Snowy-Hydro snowcourse at Spencers Creek did not exceed one metre until after the coldest period of the winter of 2012 and on 5 July the average depth was 85.3 cm. The average hourly temperature in the Stevenson Screen at Charlotte Pass (<2 km away to the south-west) for the period 5-7 July was -7.6ºC, with 6 July being the coldest day with an average temperature of <-10ºC, over the full 24 hours with the minimum temperature falling close to -17ºC. In spring 2012 at Spencers Creek there were 50+ symptomatic *Nematolepis ovatifolia*. Snowgums, *Eucalyptus niphophila*, also showed evidence of foliage death; mature tree canopies were unaffected as were seedlings, with most of the leaf die off on saplings in a band at or above about 75-80 cm. This height band of dead leaves on snowgum saplings was found at a number of sites throughout the spring.

Shrubs at the three highest elevations measured all averaged less than 70 cm in height and showed no evidence of leaf damage from this cold period (Fig. 3). On 4 July 2012 at the Kostex site, snow depth averaged 75.3 cm and the top leaves of *Eucalyptus niphophila* seedlings were exposed above the snow, but *Nematolepis ovatifolia* (average 62 cm height) were buried. On 28 December when the site was monitored, seedlings of *Eucalyptus niphophila* had dead leaves at a height of 65-70 cm but *Nematolepis ovatifolia* were unaffected. At a slightly lower elevation, and just within the treeline ecotone, shrubs averaged >73 cm in height and were badly affected. Below this, populations at the same elevations, two centred on 1720 m and two on 1750 m had affected and unaffected shrubs (Fig. 3).

Pathogens

Out of the 26 samples tested, *Phytophthora cambivora* (Petri) Buisman, (1927) was isolated from the one washed root sample with lesions from Charlotte Pass sampled in 2012, and one of the five root/soil samples (from Thredbo) in 2013. Laboratories were unable to isolate any *Phytophthora* species from the 20 soil samples taken in 2014.

Monitoring sites

Of the 120 plants monitored in the preliminary paired phosphite trials, 117 plants were re-located and 105 were assessed as having recovered regardless of whether they were in the control or treatment. Most monitored plants shed their affected leaves and no new leaves appeared to be affected. Of the 12 plants that continued to decline in health, 10 originally had advanced symptoms and only two plants proceeded from minor symptoms to major. Recovery of *Nematolepis ovatifolia* was also evident at the Whites River population. Of 74 plants recorded as either symptomatic or affected in December 2014, 28 were still assessed as affected in March 2015, 46 had recovered. Only three plants recorded as unaffected in December 2014 were recorded as affected in March 2015.

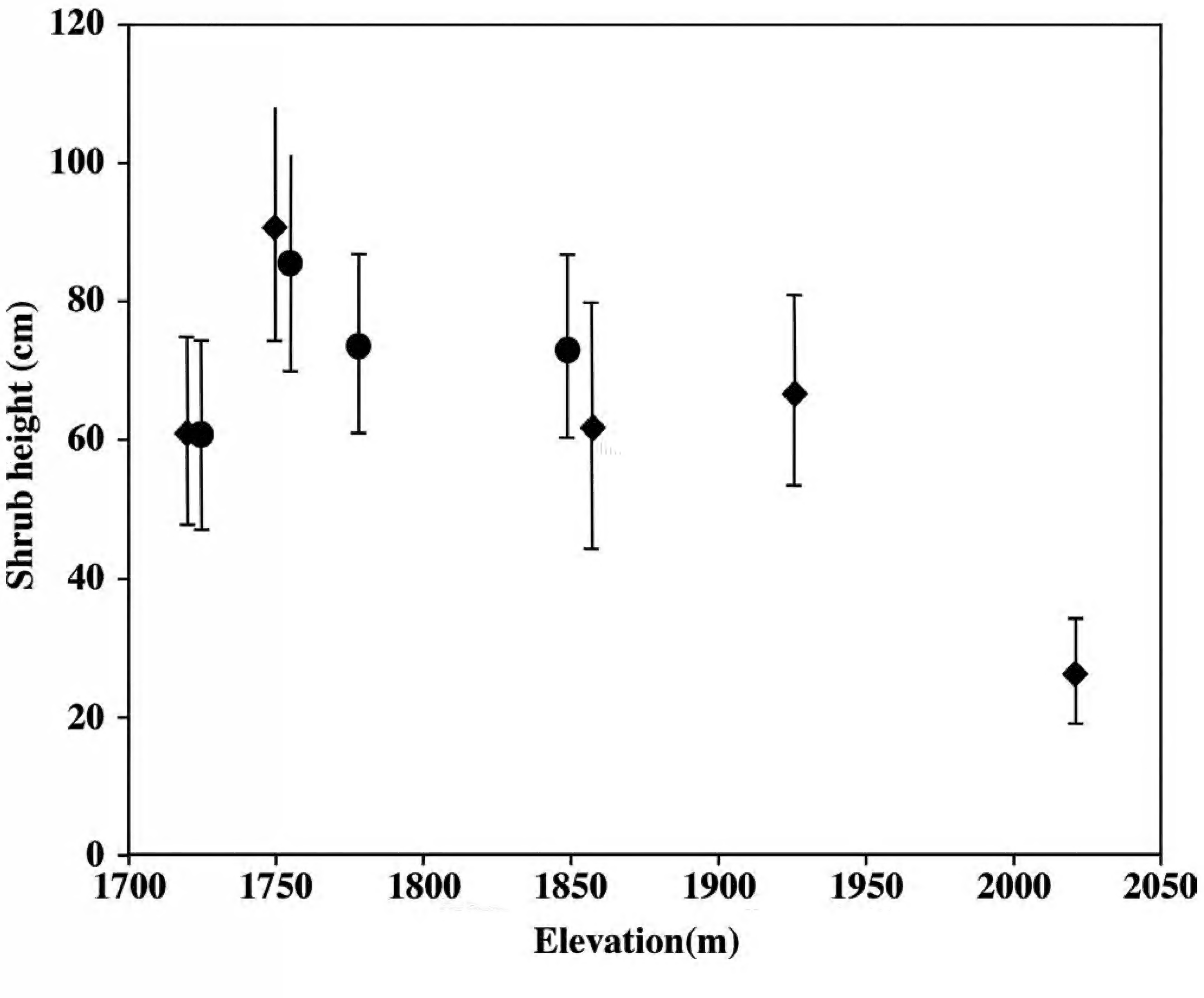

Figure 3. Shrub height ± SD of *Nematolepis ovatifolia* at locations with suspected frost damage (Circles) and without damage (Diamonds).

Discussion

Following the initial discovery of advanced dieback symptoms in shrubs, early symptoms of dieback were found across almost the entire range of *Nematolepis ovatifolia.* However, there appeared to be more than one agent responsible. Later, after a wet summer, most shrubs with suspicious symptoms in monitored sites were assessed as unaffected, whereas definitely affected shrubs proceeded towards complete death. For most shrubs in monitored sites the leaves on the affected tips were shed and the plants recovered with no hint of chlorosis. So the suspicious symptoms have not proven to be unequivocally due to *Phytophthora*, nor necessarily to lead to death. The suspicious symptoms could in some cases have been frost damage after shallow snow early in the winter season. Insect attack was noted on many shrubs, predominantly in the family Astercaeae but the same lepidopteran larvae were also collected from *Nematolepis ovatifolia.* Above and around Thredbo, large areas of *Nematolepis ovatifolia* had been stripped of all leaves except a few bound together by silk at the top of the branch, these leaves were commonly still green and hence the loss of leaves could not be confused with those damaged by frost or having early symptoms of *Phytophthora* infection.

Killing frost

Conditions in early July 2012 of low air temperature with shallow snow (65-70 cm) were conducive to the killing of leaves exposed above the snow surface and in all cases damage to *Eucalyptus niphophila* was at this height. High elevation populations of *Nematolepis ovatifolia* were mainly protected beneath the snow surface but at lower elevations where shrubs were taller they were exposed to frost damage. Shrubs above the winter snowline affected by frost in 1982 mainly recovered (pers. obs.). Similarly, seedlings of *Eucalyptus niphophila* can survive many years at about shrub height, despite repeated frost-killing of exposed leaves above the snow (Wimbush & Forrester 1988). By contrast, in a montane frost hollow *Bossiaea foliosa* was killed by frost (Leigh *et al.* 1987), but the plant would not have had its base protected by snow cover at montane elevations. The *Nematolepis ovatifolia* which had affected tips that then progressed through death of the branch and then the shrub were unlikely to have reached that condition as a result of frost. However, those in which the affected leaves dropped and the plant itself was unaffected were possibly a result of some damage acquired just above the snow surface, most likely frost damage.

Pathogens

Phytophthora cambivora was isolated from two populations of *Nematolepis ovatifolia* in which plant death rapidly followed early symptoms of infection. *Phytophthora cambivora* is hosted by at least 30 genera in 19 families (USDA 2014). In Australia it adversely affects apple, almond and cherry trees (Bumbieris & Wicks1980; Wicks & Hall 1990). It has also been isolated from eucalypt plantations (Shearer & Smith 2000).

Although pathogen infection and plant death were mapped from Thredbo through to south of Jagungal, *Phytophthora cambivor*a was found in only two of 26 samples. It is possible that in the Snowy Mountains *Phytophthora cambivor*a may be rare in the soil because dispersing zoospores are less persistent than chlamydospores or oogonia in the soil (Vannini *et al.* 2012). Vettraino *et al.* (1999) suggested that difficulty in isolating *Phytophthora cambivora* from soil may be due to the lack of resting structures such as chlamydospores, which *Phytophthora cambivora* is not known to produce (Vannini *et al.* 2012). As *Phytophthora cambivora* generally exists mainly as a single mating type it would also be unable to produce oospores (Vannini *et al.* 2012). It is apparent from the sudden infection and death across such a widespread area that *Phytophthora cambivora* in the Snowy Mountains had survived for some years along roads and trails but, apart from along water courses below these, did not disperse greatly in the soil. Even where it has dispersed it has proven difficult to isolate from soil beneath symptomatic *Nematolepis ovatifolia* which suggests that the high elevation rhizosphere is not a favoured environment for *Phytophthora cambivora* and it may only survive in host tissues, possibly dispersing among roots of adjacent plants that are in contact rather than through the soil (Ristaino and Gumpertz 2000).

The fact that affected populations were found to be significantly closer to trails suggest that dispersal was along these access routes. Earthmoving machinery may have carried mud during the construction of these trails and most of the trails still receive some vehicle movement, a major vector for the spread of *Phytophthora cambivora* in southern Europe (Vannini *et al.* 2012). However, of four major concentrations of symptomatic plants, two (Schlinks Pass Road and the Kosciuszko Road) are surfaced with imported gravel making it difficult for current vehicles to transport mud, which is more likely on the Grey Mare Trail and Valentines Trail which are mainly just graded trails. Animals may use the trails preferentially and mud could be carried on the hooves of pigs, horses or cattle. Two of the heavily affected areas, at Charlotte Pass (gravel surface) and the Valentines Trail (soil surface), are also on the 655 km long Australian Alps Walking Track. However areas affected two or more km to the west and east of Schlinks Pass road are rarely visited by walkers; there are no nearby trails but there is evidence of past cattle grazing and current pig rooting. Similarly affected populations on the west and north side of Mt Kosciuszko show evidence of feral horse presence in recent years, particularly in muddy areas. With such widespread infection and so many possible vectors, the origin of the infestation is now difficult to determine.

Conditions high in the Snowy Mountains are generally not favourable for the survival of some *Phytophthora* species, although soils are in the same pH range of 3.65 - 4.39 as found in forest soils where oak trees were infected by *Phytophthora cambivora* (Jung *et al.* 1999). Vegetation studies undertaken from the 1940s onwards did so in the belief that the soils in the higher elevations of the Snowy Mountains were too cold for *Phytophthora cinnamomi* (Alec Costin pers. comm.). In Tasmania, Podger *et al.* (1990) concluded that *Phytophthora cinnamomi* is unlikely to be pathogenic where the annual mean temperature is < 7.5ºC. If this or a similar temperature limitation applies to *Phytophthora cambivora,* for which the optimal growth temperature is 22 to 24°C (Jung 1998), then it too would be unlikely to be pathogenic in thermal conditions high in the Snowy Mountains. At the upper limits of the montane zone the annual mean temperature was calculated for Kiandra (1395 m asl) at 6.8ºC and the Kosciusko Hotel (now Sponars, 1530 m asl) at 6.1ºC and temperatures would be lower at higher elevations in the subalpine and alpine zones (Costin 1954). Nitrogen levels in Snowy Mountains soils are also low, with concentration of nitrate of 2.8 ± 1.5 mg.kg^{-1} for a location (GLORIA 5), associated with symptomatic shrubs (Pickering & Green 2009). By contrast, Jung *et al.* (1999) found mean nitrate concentrations in soils of infected oak stands of 35.6 ± 40.5 mg.kg^{-1}. Unlike many mountain areas worldwide, alpine humus soils are the dominant soil type at high elevation in the Snowy Mountains (Costin 1954) and alpine soils contain a high diversity of root endophytes (Davies & McLean 2002). Such soils with high biodiversity can suppress soil-borne fungal diseases through competition (Altieri 1999). So high elevations in the Snowy Mountains are generally not suitable for *Phytophthora* infection and the question remains, why did dieback erupt in spring 2012?

Climate

Given the widespread locations of affected populations it appears that *Phytophthora cambivora* has been present for some time, but has been held in check by some factor. Disease due to *Phytophthora* induced dieback is not usually associated with high mountain environments (McDougall *et al.* 2003). Essentially the soils are too cold. At the alpine treeline, the growing season mean shaded soil temperature at 10 cm depth is virtually identical to the seasonal mean treeline air temperature (Körner 2012, p. 36) at 6.4 ±0.7°C (SD) (Körner and Paulsen, 2004). The growing season mean air temperature (October to May) at the alpine treeline (Charlotte Pass) was recorded as 6.6°C (Costin 1954) and shaded soil temperatures above the alpine treeline in the Snowy Mountains are normally below about 7°C (Green & Stein 2015). An abundance of soil moisture favours *Phytophthora cambivora* (Day 1938). However, the infected plant may not require much water uptake in wet periods. The first signs of dieback in *Nematolepis ovatifolia* were found retrospectively from photographs taken in May 2011. Backgrounds to these photographs contained large areas of *Nematolepis ovatifolia* with limited occurrence of symptoms on plants that were subsequently to show signs of infection, chlorosis and die. If they were already infected at that time the reason that major observable symptoms of water stress were not exhibited was possibly due to the abundance of water.

The diminishing incidence of symptomatic plants with elevation above the alpine treeline suggests that at higher elevations lower soil temperatures are still holding infection in check, whereas at lower elevations rising soil temperature has made conditions suitable for infection. From 2010/11 onwards, climate patterns Australia-wide were characterised by both unusually high rainfall and temperatures. The growing seasons 2010/11 and 2011/12 were covered by the period April 2010 to March 2012, which was Australia's wettest two-year period on record and 2011 and 2012 were both in the three warmest La Nina years on record (BOM 2012). Precipitation at Thredbo over the growing season (October to May) averaged 791±192 mm (SD) in the 13 years immediately preceding the La Nina years and virtually doubled that with 1460 mm and 1456 mm in the two La Nina growing seasons (BOM 2015). At 10 cm soil depth beneath *Nematolepis ovatifolia* that was subsequently infected, temperature from growing season 2004/05 to 2009/10 averaged 7.75±0.6°C (SD), but were 8.6°C and 8.3°C in the two La Nina growing seasons (2010/11 and 2011/12). Ink disease, caused by *Phytophthora cambivora*, develops rapidly in excessively wet soils (Černý *et al.* 2008). Hence the summer period when soil temperatures were high would have corresponded with a period of high soil moisture, a situation that similarly preceded shrub dieback at Barrington Tops (McDougall *et al.* 2003).

From September 2012 precipitation declined, but the period to August 2013 was the warmest 12 month period on record in Australia (1.11°C above the long term average), a record that was exceeded the following month with the hottest September on record bookending a new record warmest 12 month period (1.25°C above the long term average). By the end of May 2014 the warmest 24 months on record in Australia had been achieved (BOM 2014). These temperature records were reflected locally with a growing season mean soil temperature of 9.2°C, recorded from the GLORIA site in 2012/13. So a wet and warm period, when conditions were suitable for rapid development and infection by *Phytophthora cambivora*, was followed by a hot, dry period when plants, deprived of root hairs, were placed under severe water stress and died rapidly.

It has been suggested that, with predicted further climatic warming and loss of snow at lower elevations (Whetton 1998; Hennessy *et al.* 2008), shrub cover may increase in alpine and subalpine areas currently dominated by herbs and graminoids, within one to two decades (Pickering & Green 2009). Because of climatic warming, a number of long-term monitoring sites have been established to measure vegetation response ranging from experimental warming of shrubs and herbs (Itex) (Wahren *et al.* 2013) and tree establishment above treeline (Kostex) (Green unpublished data) to observational (GLORIA) (Pickering & Green, 2009). However, elevational tree or shrub advance cannot be taken as inevitable because there are some factors whose actions occur infrequently, such as summer drought in 1965 and 1978 (Wimbush & Costin 1979) and 2002/03 (Morgan 2004) or drought following severe frosts in 1982/83 (Williams 1990). Frost damage and possible death of shrubs, due to cold nights without cloud cover accompanied by lack of snow, is one condition that could become exacerbated by climate change. It is unlikely that shrubs would be able to survive in areas where they are more likely to be affected adversely by severe frosts. In tundra areas in general, heath is more dependent upon the protection of deeper snow than are herbs (Billings 1973).

Higher soil temperature in the growing season allowing growth of *Phytophthora* species is another consequence of climate change. In Europe, for example, outbreaks of *Phytophthora cambivora* in the late 20th and early 21st century may have been facilitated by climate change (Vannini *et al*. 2012). Even in the subantarctic, dieback of the cushion plant *Azorella macquariensis* on Macquarie Island is believed to be due to increased infection by a pathogen with ongoing climate change (Whinam *et al.* 2014). Podger *et al.* (1990) in Tasmania concluded that an increase in mean annual temperature of 4.8°C would be required to make the highest Tasmanian alpine plants vulnerable to *Phytophthora cinnamomi*. Similar calculations have not been made for the high alpine plants in the Snowy Mountains, nor for *Phytophthora cambivora.* However, the Snowy Mountains treeline temperature in 2012/13 was ~3.8°C higher than the long term (1921–1995) growing season mean treeline temperature for Tasmania (Green & Stein 2015) and it appears that the temperature range required for *Phytophthora cambivora* to become infectious has already been achieved at these lower elevations. Hence the long-term future of high elevation shrubs will be more complex than previously thought.

Acknowledgements

Thanks to Brett Spunner for GIS and drawing Figure 2, Wayne Robinson for providing statistical advice and Thomas Wallenius for identifying Lepidopteran larvae. Thanks to Alec Costin and Dane Wimbush for an historical discussion on *Phytophthora* in the Snowy Mountains. Thanks in particular to Keith McDougall for discussions about *Phytophthora*, coming into the field to collect root sample for analysis and commenting on the manuscript. Catherine Pickering also for commenting on the manuscript

References

Altieri, M.A. (1999) The ecological role of biodiversity in agroecosystems. *Agriculture, Ecosystems & Environment* 74, 19–31.

Australian National Herbarium (2015) http://www.cpbr.gov.au/cpbr/herbarium

Billings, W.D. (1973) Arctic and alpine vegetations: similarities, differences and susceptibility to disturbance. *Bioscience* 23, 697-704.

BOM (Bureau of Meteorology) (2012) http://www.bom.gov.au/climate/enso/history/ln-2010-12/

BOM (Bureau of Meteorology) (2014) http://www.bom.gov.au/climate/updates/articles/a005-sep-2013-warmest-on-record.shtml.

BOM (Bureau of Meteorology) (2015) http://www.bom.gov.au/climate/data/stations/ accessed 12 July 2015

Bumbieris, M. & Wicks, T.J. (1980) *Phytophthora cambivora* associated with apple trees in South Australia *Australasian Plant Pathology* 9, 114.

Černý, K., Gregorová, B., Strnadová, V., Tomšovský, M., Holub, V. & Gabrielová, S. (2008) *Phytophthora cambivora* causing ink disease of sweet chestnut recorded in the Czech Republic *Czech Mycology* 60, 265–274.

Clarke, P.J., Keith, D.A., Vincent, B.E. & Letten, A.D. (2015) Post-grazing and post-fire vegetation dynamics: long-term changes in mountain bogs reveal community resilience. *Journal of Vegetation Science* 26. 278-290.

Costin, A.B. (1954) *A Study of the Ecosystems of the Monaro Region of New South Wales*. Government Printer, Sydney.

Costin, A.B. (1959) Vegetation of high mountains in Australia in relation to land use. In: *Biogeography and Ecology in Australia* (ed A. Keast), pp. 427-451 Dr. W. Junk, The Hague.

Costin, A.B, Gray, M., Totterdell, C.J. and Wimbush, D.J. (2000) *Kosciuszko Alpine Flora*. (2nd Edition). CSIRO, Melbourne.

Davies, P.W. & McLean C.R. (2002) Diversity of alpine root endophytes of Epacridaceae. In: *Biodiversity in the Snowy Mountains* (ed K. Green) pp 4-7. Australian Institute of Alpine Studies, Jindabyne.

Day, W.R. (1938) Root-rot of sweet chestnut and beech caused by species of Phytophthora: I. Cause and symptoms of disease: its relation to soil conditions. *Forestry* 12, 101-116.

Doherty, M.D., Wright, G. & McDougall, K.L. (2015) The flora of Kosciuszko National Park, New South Wales: Summary and overview. *Cunninghamia* 15, 13-68.

Donato, D.C. (2013) Limits to upward movement of subalpine forests in a warming climate. *Proceedings of the National Academy of Sciences* 110, 7971–7972.

Green, K. & Osborne W.S. (1994) *Wildlife of the Australian Snow Country*. Reed, Sydney.

Green, K. & Osborne, W.S. (2012) *Field Guide to Wildlife of the Australian Snow Country*. New Holland Publishers, Chatswood.

Green, K. & Stein, J.A. (2015) Modeling the thermal zones and biodiversity on the high mountains of Meganesia: the importance of local differences. *Arctic, Antarctic and Alpine Research* 47, 669–678.

Hardy, G.E.St.J., Barrett, S. & Shearer, B.L. (2001) The future of phosphite as a fungicide to control the soilborne plant pathogen *Phytophthora cinnamomi* in natural ecosystems. *Australasian Plant Pathology* 30, 133–139.

Hennessy, K.J., Whetton, P.H., Walsh, K., Smith, I.N., Bathols, J.M., Hutchinson, M. & Sharples, J. (2008) Climate change effects on snow conditions in mainland Australia and adaptation at ski resorts through snowmaking. *Climate Research* 35, 255-270.

Jung, T. (1998) Die Phytophthora-Erkrankung der europäischen Eichenarten – wurzelzerstörende Pilze als Ursache des Eichensterbens. Lincom Europe, München. (cited in Jung et al. 1999).

Jung, T., Blaschke, H. & Oßwald, W. (1999) Involvement of *Phytophthora* species in central and western European oak decline and the influence of site factors and nitrogen input on the disease. In: *Phytophthora Diseases of Forest Trees. Proceedings from the First International Meeting on Phytophthoras in Forest and Wildland Ecosystems,* (eds Everett, M. Hansen, E.M. & Sutton, W.) pp 28-33. Forest Research Laboratory, Oregon State University Corvallis, Oregon.

Körner, C. (2012) *Alpine Treelines—Functional Ecology of the Global High Elevation Tree Limits.* Springer, Basel.

Körner, C., & Paulsen, J. (2004) A world-wide study of high altitude treeline temperatures. *Journal of Biogeography* 31, 713–732.

Leigh, J.H., Wimbush, D.J., Wood, D.H., Holgate, M.D., Slee, A.V., Stanger, M.G. & Forrester, R.I. (1987) Effects of Rabbit Grazing and Fire on a Subalpine Environment. I. Herbaceous and Shrubby Vegetation. *Australian Journal of Botany* 35, 433-464.

McDougall, K.L., Summerell, B.A., Coburn, D. & Newton, M. (2003) *Phytophthora cinnamomi* causing disease in subalpine vegetation in New South Wales. *Australasian Plant Pathology* 32, 113–115.

McDougall, K.L., Walsh, N.G. & Wright, G.T. (2015) Recovery of treeless subalpine vegetation in Kosciuszko National Park after the landscape-scale fire of 2003. *Australian Journal of Botany* 63, 597-607.

Morgan, J.W. (2004) Drought-related dieback in four subalpine shrub species, Bogong High Plains, Victoria. *Cunninghamia* 8, 326-330.

NPWS (NSW National Parks & Wildlife Service) (2015) http://www.environment.nsw.gov.au/parkinfo/barringtontopsnpphytophthora.htm (accessed 20/7/2015)

National Herbarium of New South Wales (2015) PlantNet Online plant information. Royal Botanic Gardens Sydney http://plantnet.rbgsyd.nsw.gov.au

Office of Environment and Heritage (2015) NSW Office of Environment and Heritage, Department of Premier and Cabinet: OEH Atlas of NSW Wildlife.

Pickering, C.M. & Green, K. (2009) Vascular plant distribution in relation to topography, soils and micro-climate at five GLORIA sites in the Snowy Mountains, Australia. *Australian Journal of Botany* 57, 189-199.

Podger, F.D., Mummery, D.C., Palzer, C.R. & Brown, M.J. (1990) Bioclimatic analysis of the distribution of damage to native plants in Tasmania by *Phytophthora cinnamomi*. *Australian Journal of Ecology* 15, 281 – 289.

Raffa, K.F., Powell, E.N. & Townsend, P.A. (2012) Temperature-driven range expansion of an irruptive insect heightened by weakly coevolved plant defenses. *Proceedings of the National Academy of Sciences* 110, 2193-2198.

Ristaino, J.B. & Gumpertz, M.L. (2000) New frontiers in the study of dispersal and spatial analysis of epidemics caused by species in the genus *Phytophthora*. *Annual Review of Phytopathology* 38, 541-576.

Shearer, B.L. & Smith, J.W. (2000) Diseases of Eucalypts caused by soilborne species of *Phytophthora* and *Pythium*. In: *Diseases and Pathogens of Eucalypts* (eds Keane, P.J. Kile, G.A., Podger, F.D. & Brown, B.N.) pp 259-291. CSIRO Publishing, Collingwood.

USDA (United States Department of Agriculture) (2014) http://www.phytophthoradb.org/species.php?a=dv&id=124252 (accessed 13 June 2014)

Vannini, A., Breccia, M., Bruni, N., Tomassini, A. & Vettraino, A.M. (2012) Behaviour and survival of *Phytophthora cambivora* inoculum in soil-like substrate under different water regimes. *Forest Pathology* 42, 362–370.

Vettraino, A.M., Natili, G., Anselmi, N. & Vannini, A. (1999) Recent advances in studies on *Phytophthora* species associated with *Castanea sativa* and *Quercus cerris* in Italy. In: *Phytophthora Diseases of Forest Trees. Proceedings from the First International Meeting on Phytophthoras in Forest and Wildland Ecosystems,* (eds Everett, M. Hansen, E.M. & Sutton, W.) pp34-36. Forest Research Laboratory, Oregon State University Corvallis, Oregon.

Wahren, C.-H., Calmac, J.S., Jarrad, F.C., Williams, R.J., Papst, W.A. & Hoffmann, A.A. (2013) Experimental warming and long-term vegetation dynamics in an alpine heathland. *Australian Journal of Botany* 61, 36–51.

Whinam, J., Abdul-Rahman J.A., Visoiu, M., di Folco, M.-B.F. & Kirkpatrick, J.B. (2014) Spatial and temporal variation in damage and dieback in a threatened subantarctic cushion species. *Australian Journal of Botany* 62, 10-21.

Whetton, P.H. (1998) Climate change impacts on the spatial extent of snow-cover in the Australian Alps. In: *Snow: a Natural History; an Uncertain Future* (ed Green, K.) pp 195-206. Australian Alps Liaison Committee, Canberra.

Wicks, T. & Hall B. (1990) Evaluation of phosphonic (phosphorous) acid for the control of *Phytophthora cambivora* on almond and cherry in South Australia *Australasian Plant Pathology* 19, 132-133.

Williams, R.J. (1990) Growth of subalpine shrubs and snowgrass following a rare occurrence of frost and drought in south-eastern Australia. *Arctic and Alpine Research* 22, 412-422.

Williams, R.J. & Ashton, D.H. (1988) Cyclical patterns of regeneration in subalpine heathland communities on the Bogong High Plains, Victoria. *Australian Journal of Botany* 36, 605-619.

Wimbush, D.J. & Costin, A.B. (1979) Trends in vegetation at Kosciusko. III. Alpine range transects, 1959-1978. *Australian Journal of Botany* 27, 833-871.

Wimbush, D.J. & Forrester, R.I. (1988) Effects of rabbit grazing and fire on a subalpine environment. II. Tree vegetation. *Australian Journal of Botany* 36, 287-298.

Manuscript accepted 21 December 2015

Date of Publication:
March 2016

Cunninghamia
A journal of plant ecology for eastern Australia

The Royal
Botanic Garden
Sydney

ISSN 0727-9620 (print) • ISSN 2200-405X (Online)

An observation of adult parasitic wasps (Diapriidae sp.) visiting *Melichrus urceolatus* (Ericaceae) flowers in an endangered woodland remnant

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Abstract: *Melichrus urceolatus* R.Br. (family Ericaceae) (Urn heath) is a small shrub endemic to eastern Australia found in open grassy woodlands and heath from southern Queensland to central Victoria. Very little is known of its ecology, particularly in relation to its pollination and reproductive strategies. Most *Melichrus* species are thought to be animal-pollinated, but some floral traits of *Melichrus urceolatus* suggest wind pollination. Here, I describe an observation of parasitic wasps (Diapriidae sp.) found inside *Melichrus urceolatus* flowers in a Box-Gum Grassy Woodland remnant in Albury, New South Wales and discuss the ecological significance of the observation.

***Cunninghamia* (2016) 16: 11-14**
doi:10.7751/cunninghamia.2016.16.002

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Introduction

Melichrus urceolatus R.Br. (Urn heath) (family Ericaceae -subfamily Styphelioideae) is a small, prickly shrub endemic to eastern Australia. It is the most common and widespread of the *Melichrus* species, and is found from southern Queensland to central Victoria in patches of the critically endangered White Box – Yellow Box – Blakely's Red Gum Grassy Woodlands and Derived Native Grassland communities, hereafter Box – Gum Grassy Woodlands (Department of Environment and Heritage 2006). It is a successful post-fire resprouter (Knox & Clarke 2004). This is a common persistence strategy in fire-prone plants that generally develops at the expense of seed set and reproduction (Lamont & Wiens 2003) and could partly explain why it is difficult to propagate *Melichrus urceolatus* from seed (Hawkeswood 1977).

There is very little information on the pollination and reproductive ecology of *Melichrus urceolatus*, although seeds are thought to be dispersed by animals through ingestion of the fleshy drupes (McIntyre et al. 1995). Other species in the ericad subfamily Styphelioideae are thought to be animal-pollinated (Ladd 2006; Johnson 2012). Grant (1949) lists *Melichrus* as a bird-pollinated genus and Lepschi (1993) observed the birds, eastern spinebill (*Acanthorhyncus tenuirostris*) and white-eared honeyeater (*Lichenostomis lecuoyis*) drinking nectar from *Melichrus urceolatus* flowers (therefore potentially acting as pollinators). More recently, flies or bees have been named as the most likely pollinators of *Melichrus urceolatus* (Johnson 2012, 2013). However, *Melichrus urceolatus*' combination of floral traits suggest a more complex reproductive strategy. It produces very small (4-5 mm) pale green to creamy-white urn-shaped flowers, a colour and size trait combination that should make them almost invisible to insect pollinators (Faegri and van der Pijl 1979). In such cases, floral scent and patterns visible under ultraviolet light may compensate by acting as insect attractants (Faegri and van der Pijl 1979), but no information on these characteristics is available for *Melichrus urceolatus*. Flowers produce monad pollen units, a trait common in wind-pollinated plants (Furness 2009), but also have introrse anthers with an appendage at the base, a morphological trait that suggests trigger deposition of pollen onto flower visitors (Paterson 1961; Hermann and Palser 2000). Flowers also bloom from late autumn to early spring when fewer insect pollinators are active, yet they produce large quantities of nectar (Hawkeswood 1977), which is a primary floral attractant for animal pollinators (Faegri and van der Pijl 1979). Here, I report an observation of *Melichrus urceolatus* flower visitation by a parasitic wasp (Diapriidae sp.) and discuss the ecological significance of this observation in light of the plant's floral traits.

Study location and observation

The observation was made in late July 2015 in the Eastern Hill Reserve, an urban reserve in Albury, New South Wales (-36.08332°, 146.936797°, approx. 235 m above sea level). The reserve is a remnant area of Box – Gum Grassy Woodland. Albury experiences hot, dry summers and cool winters. In July, daily temperatures range from a mean minimum of 3.1°C to a mean maximum temperature of 13.1°C and monthly mean rainfall is 65.1 mm. On the day of the observation, the temperature reached 13.8°C (Bureau of Meteorology 2015).

On the afternoon of July 31 2015 I found three *Melichrus urceolatus* plants flowering adjacent to a walking track in the reserve. No other individuals of this species were found nearby. Upon inspection of the flowers, I found two adult parasitic wasps inside two separate flowers (Figure 1). The two wasps appeared to be the same species (later identified as a Diapriidae species by Dr Ken Walker, Museum Victoria -an adult specimen was collected and lodged at Museum Victoria). I watched the wasps for approximately twenty minutes, in which time they remained inside their respective flowers. They moved around inside the corolla very slowly, with frequent periods of inactivity. Both corollae were filled with nectar, but I could not determine whether pollen had been deposited on the wasps' bodies. I returned two days later, and found another individual (or one of the same from the previous observation) inside another flower, exhibiting the same behaviour. I conducted about 8 random observations (5-10 minutes) over the next four weeks at varying times during daylight hours, and did not observe other diurnal insects or birds visiting flowers during those visits.

Discussion

Adults of most parasitic wasp species feed on nectar and pollen and some are important pollinators of Australian flora (Armstrong 1979). Diapriid wasps have been documented as pollinators of orchid species in Japan and North America (Ferguson & Donham 2001; Sugiura & Takahashi 2015), but I could find no record of flower visitation by Diapriidae species in Australia.

My observation raises some interesting questions. *Melichrus urceolatus* is assumed to be animal-pollinated, most likely by flies and bees (Johnson 2012), and flowers produce large quantities of nectar, which certainly acts as an insect attractant. Yet the species also exhibits floral size and colour traits that suggest wind pollination. Is *Melichrus urceolatus* actually wind-pollinated, with insect visitors being merely opportunistic nectar feeders? Or does the species employ both wind and insect pollination (ambophily) as a strategy to guarantee seed set under variable environmental conditions?

Ambophily is not well-understood, but is thought to indicate an evolutionary transition between wind and insect pollination, in either direction. The evolution of wind pollination from animal pollination is more common than the reverse scenario, and generally occurs in response to environmental changes (e.g. climate change or habitat fragmentation) that affect the reliability of insect pollination (Friedman & Barrett 2009). The Box-Gum Grassy Woodlands of eastern Australia are one of the most cleared habitat types in Australia, and numerous studies have documented the effects of habitat fragmentation on the composition of plant communities (e.g. McIntyre *et al.* 2010). Yet there is very little information on pollinator insect communities in these habitats. In particular, it is not known how fragmentation of grassy woodlands affects plant-pollinator networks.

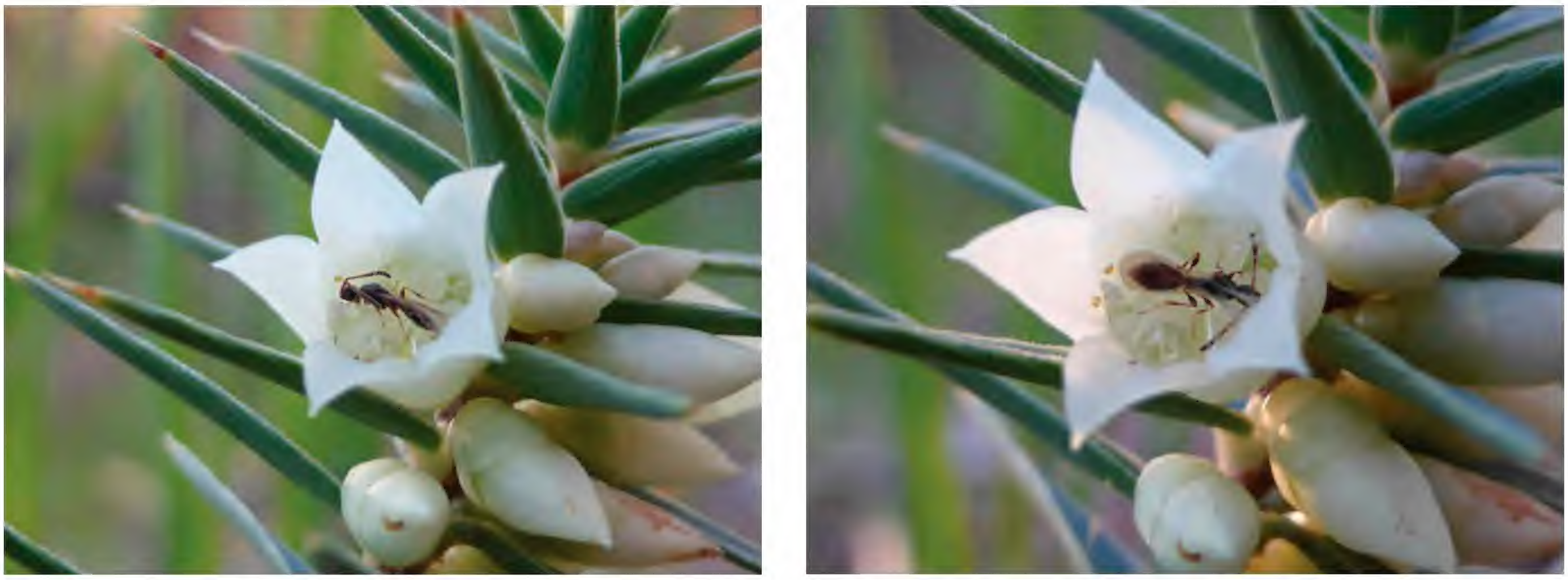
(a) (b)

Figure 1. Lateral (a) and dorsal (b) views of Diapriidae sp. wasp individual feeding inside *Melichrus urceolatus* flowers, Albury New South Wales.

Species in the ericad subfamily Styphelioideae are assumed to be exclusively animal-pollinated, but Ladd (2006) documents a transition from insect to wind pollination in some species of *Richea*, another southern hemisphere Ericaceae genus. Pollen development in the *Melichrus* genus is poorly-understood, but development in other Styphelioideae species, particularly the formation of pseudomonads, is very similar to that of the Cyperaceae, a predominantly wind-pollinated family (Furness 2009). Interestingly, recent evidence has shown that ambophily is more widespread in the Cyperaceae than previously thought, and likely indicates a transition from wind to insect pollination (Wragg & Johnson 2011). In some plants, ambophily can be a facilitative mechanism, whereby insect visitation facilitates wind pollination by triggering pollen release (e.g. Pierre et al. 2010; Mangla & Tandon 2011), which may partly explain the trigger-like anther appendage in *Melichrus urceolatus* (Paterson 1961).

This observation has highlighted an interesting combination of floral traits in *Melichrus urceolatus* and a paucity of information available on its ecology. Further detailed studies are necessary to understand pollination in this species. Evidence of ambophily in *Melichrus urceolatus* would provide an opportunity to investigate this poorly-understood pollination strategy, especially in relation to its evolutionary role under conditions of climate and land use change. Alternatively, strong evidence that *Melichrus urceolatus* is insect-pollinated (as has been suggested) including identification of the key pollinators across its geographical range, would increase understanding of how fragmentation of grassy woodlands impacts plant-pollinator networks. Regardless of its pollination syndrome, the role of *Melichrus urceolatus* as a rich source of winter nectar means it could play an important role in supporting pollinator insect communities in endangered Box-Gum Grassy Woodlands.

Acknowledgements

Thank you to Dr Ken Walker for identification assistance, and to the Editor and an anonymous referee who helped to improve an earlier version of this manuscript.

References

Armstrong, J.A. (1979) Biotic pollination mechanisms in the Australian flora – a review. *New Zealand Journal of Botany* 17:467-508.

BOM (2015) Climate summary statistics Albury Airport AWS, Station number 072160. URL: http://www.bom.gov.au/climate/averages/tables/cw_072160.shtml Accessed 1 November 2015.

Department of Environment and Heritage (2006) White box - yellow box - Blakely's red gum grassy woodlands and derived native grasslands. Nationally threatened species and ecological communities guidelines, EPBC Act policy statement. URL: https://www.environment.gov.au/epbc/publications/white-box-yellow-box-blakelys-red-gum-grassy-woodlands-and-derived-native-grasslands.

Faegri, K. & van der Pijl, L. (1979) *The Principles of Pollination Ecology*. Third Edition. Pergamon Press, Oxford, 244p.

Ferguson, C. & Donham, K. (2001) Parasitic wasp (Hymenoptera: Diapriidae) pollination of a protected North American slipper-orchid *Cypripedium fasciculatum* (Orchidaceae). 2001: An Entomological Odyssey of ESA, 12 December 2001, San Diego CA.

Friedman, J. & Barrett, S.C.H. (2009) Wind of change: new insights on the ecology and evolution of pollination and mating in wind-pollinated plants. *Annals of Botany* 103:1515-1527.

Furness, C.A. (2009) Pollen Evolution and Development in Ericaceae, with Particular Reference to Pseudomonads and Variable Pollen Sterility in Styphelioideae. *International Journal of Plant Sciences* 170:476-495.

Grant, V. (1949) Pollination systems as isolating mechanisms in angiosperms. *Evolution* 3:82-97.

Hawkeswood, T.J. (1977) The Genus Melichrus RBr. *Australian Plants* 10:36-39.

Hermann, P.M. & Palser, B.F. (2000) Stamen development in the Ericaceae. I. Anther wall, microsporogenesis, inversion, and appendages. *American Journal of Botany* 87:934-957.

Johnson, K.A. (2012) *Pollination Ecology and Evolution of Epacrids*. PhD Thesis, University of Tasmania.

Johnson, K.A. (2013) Are there pollination syndromes in the Australian epacrids (Ericaceae: Styphelioideae)? A novel statistical method to identify key floral traits per syndrome. *Annals of Botany* 112:141-149.

Knox, K.J.E & Clarke, P.J. (2004) Fire response syndromes of shrubs in grassy woodlands in the New England Tableland Bioregion. *Cunninghamia* 8:348-353.

Ladd, P.G. (2006) Is there wind pollination in the southern heaths (Styphelioideae, Ericaceae)? *Botanische Jahrbücher* 127:57-67.

Lamont, B.B. & Wiens, D. (2003) Are seed set and speciation rates always low among species that resprout after fire, and why? *Evolutionary Ecology* 17:277-292.

Lepschi, B.J. (1993) Food of some birds in Eastern New South Wales: Additions to Barker & Vestjens. *Emu* 93:195-199.

Mangla, Y., & Tandon, R. (2011) Insects facilitate wind pollination in pollen-limited *Crateva adansonii* (Capparaceae). *Australian Journal of Botany* 59:61-69.

McIntyre, S., Stol, J., Harvey, J., Nicholls, A.O., Campbell, M., Reid, A., Manning, A.D. & Lindenmayer, D. (2010) Biomass and floristic patterns in the ground layer vegetation of box-gum grassy eucalypt woodland in Goorooyarroo and Mulligans Flat Nature Reserves, Australian Capital Territory. *Cunninghamia* 11:319-357.

McIntyre, S., Lavorel, S. & Tremont, R.M. (1995) Plant life-history attributes: their relationship to disturbance response in herbaceous vegetation. *Journal of Ecology* 83:31-44.

Paterson, B.R. (1961) Studies of floral morphology in the Epacridaceae. *Botanical Gazette* 122:259-279.

Pierre, J., Vaissière, B., Vallée, P. & Renard, M. (2010) Efficiency of airborne pollen released by honeybee foraging on pollination in oilseed rape: a wind-insect assisted pollination. *Apidologie* 41:109-115.

Sugiura, N. & Takahashi, H. (2015) Comparative pollination biology in two sympatric varieties of *Cypripedium macranthos* (Orchidaceae) on Rebun Island, Hokkaido, Japan. *Plant Species Biology* 30:225-230.

Wragg, P.D. & Johnson, S.D. (2011) Transition from wind pollination to insect pollination in sedges: experimental evidence and functional traits. *New Phytologist* 191:1128-1140.

Manuscript accepted 21 December 2015

Date of Publication:
June 2016

Cunninghamia

A journal of plant ecology for eastern Australia

The Royal
Botanic Garden
Sydney

ISSN 0727-9620 (print) • ISSN 2200-405X (Online)

Hunter Valley Weeping Myall Woodland – is it really definable and defendable with and without Weeping Myall (*Acacia pendula*)?

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Abstract: Hunter Valley Weeping Myall Woodland is listed as a Critically Endangered Ecological Community (CEEC) under both the New South Wales *Threatened Species Conservation (TSC) Act 1995* and the Commonwealth *Environment Protection and Biodiversity Conservation (EPBC) Act 1999*. Uncertainty regarding the provenance of Weeping Myall (*Acacia pendula*) in the Hunter has led to questioning of the place of Hunter Valley Weeping Myall Woodland CEEC in State and Commonwealth legislation. A recent publication has endorsed its legislative listing, largely based on the co-association of Weeping Myall with a range of other semi-arid species in some parts of the Hunter Valley. We counter this argument and show that the semi-arid species present in low rainfall areas on Permian sediments of the Hunter Valley floor are in fact more widespread than previously documented. Through examination of distributional records, we demonstrate that these species display no fidelity to purported Hunter Valley Weeping Myall Woodland, but instead occur in a range of other vegetation communities across much of the central and upper Hunter Valley. Habitat suitability modelling undertaken for *Acacia pendula* shows there to be nearly 900 times the 200 ha of pre-European extent, or 20 times the area of occupancy previously estimated for this community.

We also revisit an earlier ordination analysis which showed a divergence in sample data potentially representative of Hunter Valley Weeping Myall Woodland. We add new samples and provide a revised classification of the purported community, which shows that sample plots from two forms of Hunter Valley Weeping Myall Woodland are floristically indistinguishable from comparative data in 20-25 year old mining rehabilitation forests of *Eucalyptus cladocalyx*, and native grasslands derived predominantly from landscapes of *Eucalyptus crebra* and *Eucalyptus moluccana*.

Relevant legislation requires any threatened community to be identifiable based on a particular species assemblage and its area of occupancy. We question whether Hunter Valley Weeping Myall Woodland is recognisable with and without the presence of *Acacia pendula*. We argue that the identification of Hunter Valley Weeping Myall Woodland is unachievable without the visual cue of *Acacia pendula*, and note that for some time regional botanists have used this species' presence as a *de facto* diagnostic tool to identify this community; in fact, there are no examples of the community having been identified as such in the absence of *Acacia pendula*. Finally, following from our ordination results, and the presence of key diagnostic species within more widespread grassy woodlands and derived native grasslands, we suggest that 200 years of anthropogenic disturbance across the Hunter Valley has sufficiently masked any distributional pattern of western semi-arid species that might have once occurred. We contend that there is little value in conserving a purported community that cannot be confidently delineated in numerical classifications, lacks a consistent and diagnostic suite of characteristic species, and for which there is uncertainty over the origins of its dominant, flagship species, *Acacia pendula*.

Cunninghamia **(2016) 16: 15–30**
doi 10.7751/cunninghamia.2016.16.003

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Introduction

Hunter Valley Weeping Myall Woodland is listed as a Critically Endangered Ecological Community (CEEC) under both the NSW *Threatened Species Conservation Act 1995* and the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*. One of the key components of this community, Weeping Myall (*Acacia pendula*), is potentially alien to the Hunter Valley, and arguably the species has never naturally occurred there. In an earlier paper, we presented a case questioning the origins of *Acacia pendula* in the region, using historical literature, database records, voucher specimens and habitat assessments to suggest that this species was never a natural part of the Hunter flora (Bell & Driscoll 2014a). The publication of this view occurred at the time of a proposal to raise the status of Hunter Valley Weeping Myall Woodland to Critically Endangered under the *TSC Act 1995*, which highlighted a need to address inconsistencies in the perceived conservation value of this community.

In response to our concerns, Tozer and Chalmers (2015) recently argued that irrespective of the origins of *Acacia pendula*, the co-occurrence of other more western species within the Hunter Valley provides sufficient merit to maintain, and indeed elevate, legal protection for this ecological community. They accepted that there remains some uncertainty over the origins of *Acacia pendula* in the Hunter Valley, but reiterated that it is the assemblage of species, not *Acacia pendula* itself, which defines Hunter Valley Weeping Myall Woodland. Despite this sentiment, in regard to the ecological community they agree that "... *competent, experienced botanists remain unconvinced the Hunter Valley Myall Woodland constitutes an assemblage of species distinct from others occurring in the upper Hunter Valley*".

Tozer and Chalmers (2015) made a number of generalisations which we believe require clarification. The views expressed by us were based on our experience in plant ecology spanning over 25 years in the Hunter Valley, and supported with extensive evidence from the literature (see Bell & Driscoll 2014a). Over the years, we have struggled to rationalise our field experiences and observations with the legislation on this issue, culminating in the views expressed in our 2014 paper. This current note addresses three important points raised by Tozer and Chalmers (2015) which are crucial in the debate over the conservation value of Hunter Valley Weeping Myall Woodland: 1) the general ecological basis for any threatened ecological community, and how that relates to Hunter Valley Weeping Myall Woodland; 2) the co-occurrence of other western species in the Hunter Valley, and the lack of support they provide to the existence of Hunter Valley Weeping Myall Woodland; and 3) the lack of numerical classification support for Hunter Valley Weeping Myall Woodland.

For the sake of progressing debate on this issue, this paper is concerned predominantly with furthering understanding on the existence or otherwise of Hunter Valley Weeping Myall Woodland, the community. Resolving the origin of *Acacia pendula* in the Hunter Valley is not addressed further, and our earlier opinion that the species is introduced remains unchanged. In this regard, the principle question we now pose is this: Can Hunter Valley Weeping Myall Woodland be delineated in the field if *Acacia pendula* was removed from consideration? That is, on the assumption that *Acacia pendula* was absent in the pre-European Hunter Valley (as postulated in Bell & Driscoll 2014a), is the fidelity of the other co-occurring species included in the listing for this community strong enough to maintain a definable entity? If such an entity does exist, does it warrant formal protection in legislation, or have anthropogenic impacts been so great over the last 200 years that we are too late in our attempts to protect and conserve what at best could be described as a functionally extinct community?

The ecological basis for a threatened community

Ecological communities require logical and definable boundaries so that they can withstand legal scrutiny and can be managed effectively. In their review, Tozer and Chalmers (2015) rightly recognise that together with certain environmental factors, threatened species legislation typically defines a community as an "assemblage of species occupying a particular area", although not all species included in a determination can be expected at all locations. They also highlight the potential confounding impacts on biogeographical landscape patterns that may arise following 200 years of anthropogenic disturbance, as has occurred in the Hunter Valley of New South Wales. The relative scarcity of systematic and quantitative survey data leads them to question the ecological basis for recognising Hunter Valley Weeping Myall Woodland as a distinct community. These are all valid points, since it is difficult for consistent and observable patterns in species distribution to be recognised from highly disturbed landscapes with few data.

To answer their question, Tozer and Chalmers (2015) discuss thirteen western taxa which have similar distribution patterns to the Hunter occurrence of *Acacia pendula*, alluding to the role this suite of species collectively plays as evidence for the movement of western species through the Goulburn Valley corridor. Seven of these in particular (*Calocephalus citreus, Acacia melvillei, Enteropogon acicularis, Eragrostis alveiformis, Enchylaena tomentosa, Lysiana exocarpi* subsp. *tenuis, Chenopodium glaucum*) are noted as displaying a more restricted distribution akin to that shown by *Acacia pendula*. Based on data from the Atlas of Living Australia, they suggest that the area encompassed by these species generally lies between Broke, Singleton, Muswellbrook and Sandy Hollow. Correlating the distributions of these species with annual rainfall, geology and topography, they observe that a natural truncation in occurrence is present just west of Sandy Hollow, where the Triassic Narrabeen sandstones converge along the Goulburn River Valley. At this locality, the Goulburn River valley exhibits a rain shadow effect, and reportedly forms part of the Goulburn Valley corridor which potentially facilitates the easterly movement of western species.

Using our own systematic plot data from the Hunter Valley collected over 20 years of sampling, we tested the assumption that these seven species show a restricted distribution within the Hunter, and that (by extension) they can be used in support of Hunter Valley Weeping Myall Woodland. From a review of our data, it was evident that the distribution of the seven species noted above show no fidelity to mapped occurrences of Hunter Valley Weeping Myall Woodland or *Acacia pendula*, and indeed occur in a range of vegetation communities on predominantly Permian-aged substrates across a large portion of the central and upper Hunter Valley (Figure 1). In none of these communities (including Hunter Valley Weeping Myall Woodland) are they dominant, but they show a presence which is notable, not unusual. The suggestion that these species are indicative of a vegetation community characterised by *Acacia pendula* and co-occurring with a range of semi-arid species is unsupported by these data, and is perhaps an over-generalisation based on limited observations.

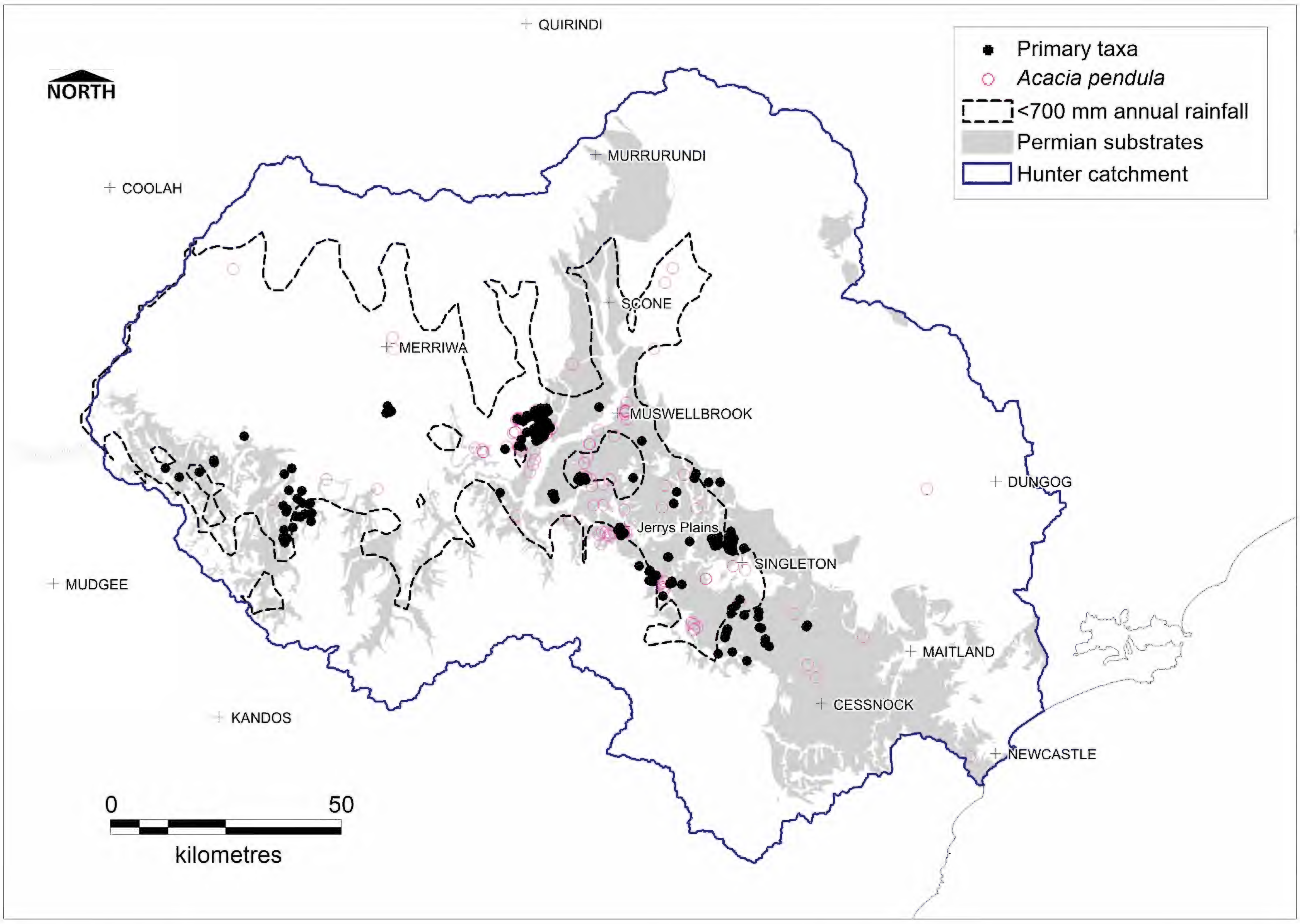

Figure 1. Regional distribution of primary key diagnostic taxa identified by Tozer & Chalmers (2015) for Hunter Valley Weeping Myall Woodland, shown with *Acacia pendula* records. Taxa included as primary taxa are *Acacia melvillei, Calocephalus citreus, Chenopodium glaucum, Enchylaena tomentosa, Enteropogon acicularis, Eragrostis alveiformis,* and *Lysiana exocarpi* subsp. *tenuis*. Data from personal database records.

As a further illustration of this point, Table 1 summarises the distribution of these seven taxa across differing vegetation types in the Hunter Valley, as extracted from our data. Rather than assign each vegetation type to broadly defined mapping units produced from the various classification projects over recent years, original field-recorded community descriptions are shown in the table. These community labels noted in the field provide a better indication of exactly where the target species occur in the landscape, and have not been compromised to accommodate a broader classification. Quite clearly, the combination of species nominated in Tozer and Chalmers (2015) as being indicative of Hunter Valley Weeping Myall Woodland also occur across a wide range of other vegetation types. Three species in particular (*Calocephalus citreus, Enteropogon acicularis* and *Enchylaena tomentosa*) are common across many different vegetation types.

Derived Native Grasslands, those grasslands resulting from the partial or full removal of canopy and shrub layer and the retention of many native grasses and forbs, support five of the seven nominated species. The two remaining species are a large shrub (*Acacia melvillei*) and an aerial mistletoe (*Lysiana exocarpi*), neither of which are expected to occur within regularly grazed grassland landscapes (although the former does reappear in some grasslands where cattle have been removed). These data suggest that perhaps these seven species (and others) appear as characteristic and diagnostic for Hunter Valley Weeping Myall Woodland because they were always present in grassland and grassy woodland areas in this part of the Hunter Valley. As invasion by *Acacia pendula* has progressed, most species have been shaded out, with these few remaining as the most notable. The paucity of systematic floristic data from derived grasslands across the entire Hunter Valley limits further examination of this theory. As a guide, however, a separate dataset of 262 grassland sample plots (0.01 ha in size; unpubl. data) from former Box-Ironbark woodlands of the central and upper Hunter Valley shows, for example, that *Calocephalus citreus* has been recorded in 45 plots, *Enteropogon acicularis* in 22, *Eragrostis alveiformis* in 13, and *Enchylaena tomentosa* in 10. This demonstrates the presence of these species in derived grasslands across lands previously dominated by *Eucalyptus moluccana* and/or *Eucalyptus crebra*.

Table 1. Recorded occurrence of key Hunter Valley Weeping Myall Woodland taxa in systematic data from the Hunter Valley floor. Cc = *Calocephalus citreus*, Am = *Acacia melvillei*, Eac = *Enteropogon acicularis*, Eal = *Eragrostis alveiformis*, Et = *Enchylaena tomentosa*, Le = *Lysiana exocarpi* subsp. *tenuis*, and Cg = *Chenopodium glaucum*.

Species	Cc	Am	Eac	Eal	Et	Le	Cg
Derived Native Grassland	✓		✓	✓	✓		✓
Dawson's Box Forest	✓	✓	✓		✓		
Narrow-leaf Ironbark Grassy Forest	✓		✓		✓	✓	
Grey Box Grassy Woodland	✓		✓		✓		
Spotted Gum – Narrow-leaf Ironbark Forest	✓		✓		✓		
Spotted Gum – Red Ironbark Forest	✓		✓		✓		
Western Grey Box Grassy Woodland*	✓		✓	✓			
Grey Box – Paperbark Forest			✓		✓		
Swamp Oak Forest			✓		✓		
Forest Redgum Grassy Forest			✓		✓		
Bulloak Thicket			✓		✓		
White Box Grassy Woodland			✓		✓		
Grey Box – Black Cypress Pine Forest	✓						
Yellow Box Grassy Woodland				✓			
Fuzzy Box Grassy Woodland					✓		
Black Cypress Pine Forest			✓				
Coast Myall Low Forest					✓		
Rough-barked Apple Forest						✓	

* within the Hunter Valley but west of the Sandy Hollow truncation point noted by Tozer & Chalmers (2015).

Legal determinations for Hunter Valley Weeping Myall Woodland

In the original listing, Hunter Valley Weeping Myall Woodland comprised only eighteen plant taxa (NSW Scientific Committee 2006). All of these, including *Acacia pendula*, have been observed by us to be present across many habitats other than Hunter Valley Weeping Myall Woodland, and particularly within the surrounding State listed Central Hunter Grey Box – Ironbark Woodland, Central Hunter Ironbark – Spotted Gum – Grey Box Forest, and Hunter Valley Footslopes Slaty Gum Woodland threatened ecological communities (TECs). There are no species on this list that occur only in areas supporting *Acacia pendula*, although this fact alone does not discount the presence of a community.

More recently, the Final Determination for listing Hunter Valley Weeping Myall Woodland as Critically Endangered (NSW Scientific Committee 2016) has expanded the list of characteristic species to approximately sixty taxa. In our view this expanded list does not aid but hinders identification of this community, as it still includes a considerable number of taxa that are widespread and common across the Hunter Valley, and which are contiguous with the above-mentioned TECs. Using our dataset of systematic plot data, and in the absence of unequivocal numeric analytical support for this community, we examined the regional distribution of all taxa included in the revised description of Hunter Valley Weeping Myall Woodland.

Two of these taxa are eucalypts (*Eucalyptus crebra, Eucalyptus dawsonii*), both characteristic of three surrounding TECs, while seven are small trees (*Acacia homalophylla–Acacia melvillei* complex, *Acacia pendula, Acacia implexa, Acacia salicina, Allocasuarina luehmannii, Brachychiton populneus* subsp. *populneus, Callitris endlicheri*). The last five of these are particularly abundant and widespread across a range of habitats in the Hunter Valley, although *Acacia salicina* is most prominent between Jerrys Plains and Martindale, and extends into Ravensworth and the northern Hunter around Aberdeen and Scone. *Acacia homalophylla–Acacia melvillei* complex and *Acacia pendula* occur in several landscapes in agricultural land across the mid and upper Hunter Valley, typically as individual trees or small clumps, with records increasing sharply in recent years as grazing pressure has been removed (Bell & Driscoll 2014a).

Six shrub species included in the determination are particularly wide ranging (*Dodonaea viscosa, Maireana microphylla, Myoporum montanum, Notelaea microcarpa var. microcarpa, Psydrax odorata subsp. buxifolia, Spartothamnella juncea*), while seven others are less common but are not confined to habitat supporting *Acacia pendula* (*Acacia gunnii, Geijera parviflora, Geijera salicifolia* var. *salicifolia, Rhagodia parabolica, Sarcostemma australe, Sclerolaena muricata, Senna artemisioides* subsp. *zygophylla*). Based on available data, *Geijera parviflora* and *Rhagodia parabolica* appear more abundant around Scone in the north of the Hunter, while *Geijera salicifolia* var. *salicifolia* is prominent along both the southern and northern rims of the Valley. *Sarcostemma australe* and *Sclerolaena muricata* are rare in the Hunter, with scattered records around and north of Denman and Wybong, but are again not confined to Hunter Valley Weeping Myall Woodland.

Ground layer vegetation includes sixteen grass taxa, sixteen forbs and herbs, one each of fern, graminoid and vine, and two mistletoes. As may be expected in grassy woodland landscapes, many of these are wind-dispersed and few occupy restricted distributions in the Hunter Valley. Exceptions include *Chenopodium glaucum, Lysiana exocarpi* subsp. *tenuis*, and *Ptilotus nobilis* subsp. *semilanatus*, all represented by few records in the Jerrys Plains to Wybong area (although the last two are more widespread based on Australia's Virtual Herbarium [AVH] data). The paucity of voucher specimens of *Chenopodium glaucum* from the Hunter (a single AVH collection from a storm water drain in urban Muswellbrook, possibly introduced) suggest that this normally coastal species is very rare or absent from the central and upper Hunter. Early records of this species from eastern Goulburn River National Park, Jerrys Plains and Wybong may have been, in the absence of fertile material, mistakenly referred to the superficially similar and more common *Atriplex semibaccata*. Similarly, the coastal mistletoe *Amyema congener* subsp. *congener* is also included in the community list for Hunter Valley Weeping Myall Woodland, but these early records from the Jerrys Plains area may be misidentified *Dendrophthoe vitellina*, a superficially similar but more prevalent mistletoe species in the area. Finally, two grass species are included in the determination list but their presence as diagnostic taxa is also questioned. We have no knowledge of *Monachather paradoxus* from the Hunter Valley, and herbarium collections indicate that it occurs well west of the region (west of Dubbo); it is not present in systematic data from known stands of Weeping Myall. While rare on the Hunter Valley floor, *Poa sieberiana* is common at higher elevations on basalt and other fine-sediment substrates, and it too is absent from plot data within Hunter Valley Weeping Myall Woodland.

When assessed collectively, the vast majority of taxa purported to be characteristic of Hunter Valley Weeping Myall Woodland are in fact common and widespread across the region in many differing habitats. Those that do display restricted distributions are not confined to definable areas or habitats, but appear to be opportunistic and a reaction to anthropogenic disturbances. As a consequence, it is difficult to identify a particular suite of taxa out of these sixty that could realistically characterise Hunter Valley Weeping Myall Woodland above all other surrounding vegetation. Acknowledging the fact that an ecological community is comprised of many different species occurring in differing abundances, and in a definable biophysical envelope, the high proportion of widespread species and few species showing clear fidelity suggests little demonstrable floristic evidence to support the existence of Hunter Valley Weeping Myall Woodland.

Western conduit for species movement in the Hunter Valley

Tozer and Chalmers (2015) discuss several times the theory first postulated by Beadle (1981) that there exists a conduit for the easterly movement of flora and fauna along the Goulburn River Valley and into the Hunter. They use this to suggest that the apparent disjunct occurrence of *Acacia pendula* and other semi-arid species in the Hunter Valley may be a function of discontinuities in edaphic and climatic factors, resulting in only scattered suitable habitat for these species. This line of reasoning does not concur with habitat modelling prepared by us for *Acacia pendula* over much of the central and upper Hunter Valley. Our habitat suitability model shows that almost the entire Hunter Valley floor (~175,000 ha) provides potential habitat for *Acacia pendula* (Figure 2), and by logical extension Hunter Valley Weeping Myall Woodland. This model was prepared using Maxent version 3.3.3k (www.cs.princeton.edu/~schapire/maxent/), a well-tested and widely used software package for creating environmental niche models, and was run at a 100 metre grid resolution across a 15,530 km^2 study area. By way of validation, the Area Under the Curve (AUC) of the Receiver Operating Characteristic (ROC) returned values of 0.942 for training data and 0.929 for test data for Sensitivity vs. 1-Specificity (i.e. true positives vs. false positives). An AUC value of 1 would be a perfect model and of 0.500 would be no better than random prediction.

Based on this model, there is no edaphic and climatic niche along the southern, central section of the Hunter floor where *Acacia pendula* would be restricted. Instead, existing records predict a considerably wider distribution, nearly 900 times the estimated 200 ha pre-European distribution, or 20 times the 84 km^2 estimated area of occupancy of Hunter Valley Weeping Myall Woodland (both estimates from NSW Scientific Committee 2016). It is likely that similar modelling of other semi-arid species present in the Hunter, such as the seven highlighted by Tozer and Chalmers (2015), would show a comparable distributional pattern.

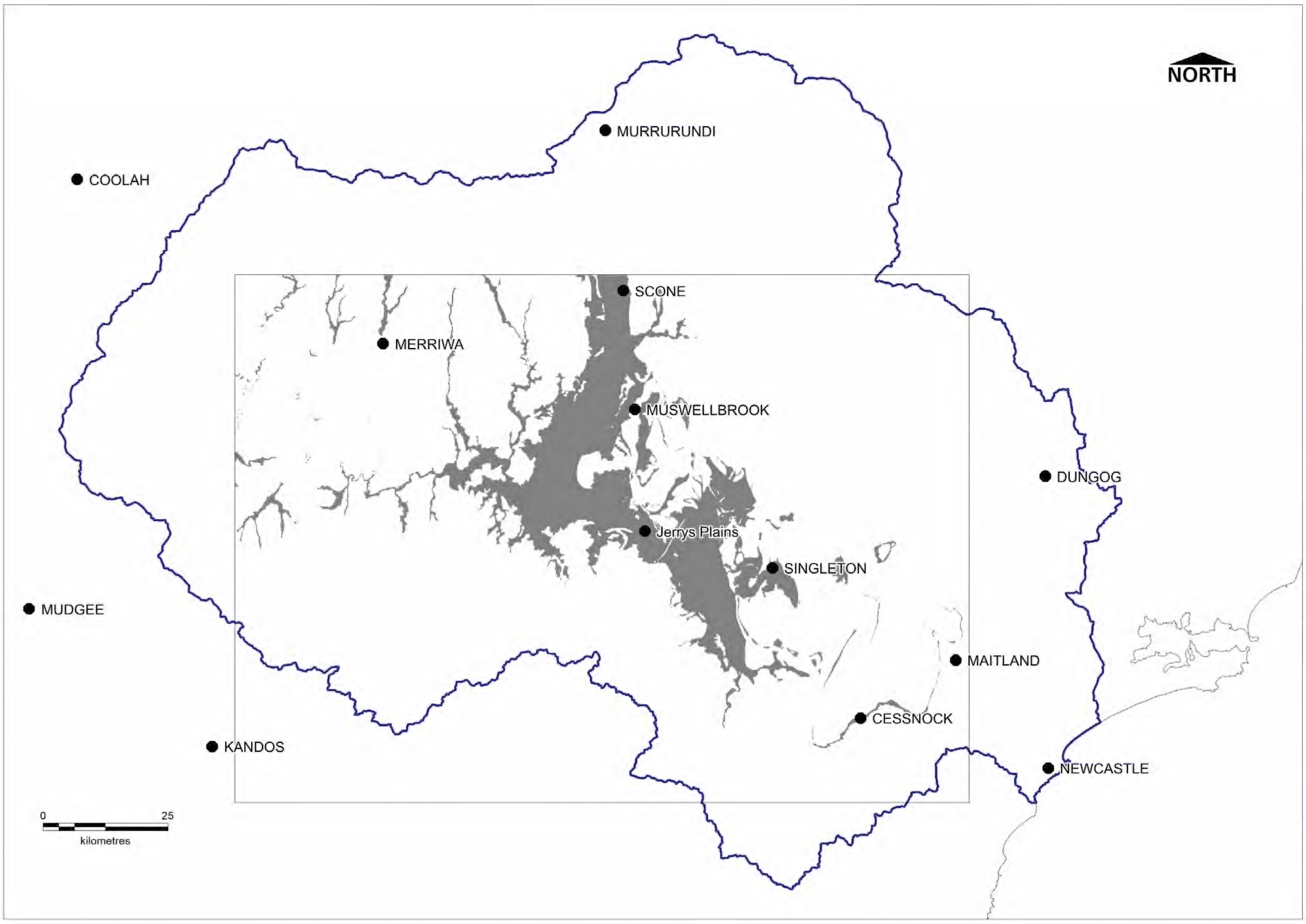

Figure 2. Habitat suitability model for *Acacia pendula*, created using Maxent at a 100 m grid resolution and utilising 78 known presence points for the species (80% used for model training; 20% for model testing). Model bounds shown. The Area Under the Curve (AUC) of the Receiver Operating Characteristic (ROC) returned values of 0.942 for training data and 0.929 for test data for Sensitivity vs. 1-Specificity. Seventy-eight records are quite sufficient for a good model, particularly as they are well dispersed.

There is, however, ample evidence that the movement of plant species from western districts has occurred into the Hunter Valley. A number of taxa are known to extend relatively close to the coast within the region, including the long-lived trees *Eucalyptus camaldulensis, Eucalyptus conica, Eucalyptus microcarpa*, and to a lesser extent *Corymbia trachyphloia* subsp. *amphistomatica*. A number of arid-zone and western *Acacia*, in addition to *Acacia pendula*, are also present in the Hunter, including *Acacia aneura, Acacia harpophylla, Acacia melvillei, Acacia homalophylla, Acacia salicina,* and *Acacia spectabilis*. But there are also many other mid layer and understorey species, in addition to those previously mentioned. These include, *Allocasuarina gymnanthera, Bothriochloa biloba, Calandrinia balonensis*, *Casuarina cristata*, *Chenopodium desertorum* subsp. *microphyllum, Cymbopogon obtectus, Dichopogon strictus, Diuris tricolor, Eragrostis lacunaria, Eulalia aurea, Goodenia cycloptera, Hakea tephrosperma, Leiocarpa panaetioides, Lomandra leucocephala* subsp. *leucocephala*, *Melaleuca lanceolata, Melaleuca uncinata, Myoporum platycarpum* subsp. *platycarpum*, *Neptunia gracilis* forma *gracilis, Panicum queenslandicum* var. *queenslandicum, Perotis rara, Persoonia curvifolia, Santalum lanceolatum, Sarcostemma australe, Scaevola albida* var. *pallida, Swainsona procumbens, Templetonia stenophylla, Triodia scariosa* subsp. *scariosa, Tylophora linearis* and *Zygophyllum apiculatum* (see http://avh.ala.org.au/). All of these species occur in suitable habitat in the upper Hunter Valley, with many extending east to the Muswellbrook and Singleton districts. A full review of all Hunter plant species would likely result in a sizeable list of taxa that extend east through the Goulburn River corridor, but only a very minor proportion of these would be associated with Hunter Valley Weeping Myall Woodland or *Acacia pendula*.

Despite the presence of large and conspicuous species such as *Eucalyptus camaldulensis, Eucalyptus microcarpa, Eucalyptus conica, Melaleuca lanceolata, Hakea tephrosperma, Santalum lanceolatum,* and *Myoporum platycarpum* subsp. *platycarpum* in the Bylong to Ulan area, there are but two records of *Acacia pendula*. Extensive surveys by us and others across private lands in these areas in recent years, extending along the valleys west from Bylong to Wollar and Ulan, have failed to replicate the density of *Acacia pendula* individuals in seemingly identical landscapes to those further east (see FloraSearch 2005, Moolarben Biota 2006, Ecovision 2008, Wells Environmental Services 2011, Bell & Driscoll 2014b).

Lack of definition through numerical classification

Despite the many numerical classifications of vegetation communities undertaken in the Hunter Valley, none have unequivocally delineated Hunter Valley Weeping Myall Woodland as a distinct community. At the time of Peake's (2006) vegetation classification of the Hunter Valley floor, he had no systematic plot data to analyse so resorted to a subjective description of the community based on limited field notes. Soon after, Umwelt (2006) documented two forms of Hunter Valley Weeping Myall Woodland at Jerrys Plains, but again this was subjectively defined. Bell (2007) performed a localised analysis of sample data collected at Jerrys Plains and Warkworth, and found a strong relationship between *Acacia*-dominated stands relative to other forest and woodland vegetation. Somerville (2009) did include Hunter Valley Weeping Myall Woodland in his classification, but only via an expert review process after finalising his numerical classification (see his Table 4.6). The subsequent classification by Sivertsen et al. (2011), leading onto the Greater Hunter Mapping Project, adopted Somerville's (2009) classification without question or further numerical interrogation.

Bell (2012) documented attempts to numerically define Hunter Valley Weeping Myall Woodland, but limited data and sampling opportunities brought into question the robustness of the results. Using ordination techniques, a divergence of samples in a regional dataset was demonstrated, suggesting that a distinct entity characterised by *Acacia pendula* may be present. However, conclusions drawn were only tentative given the low species diversity and abundances in some of the sites (18 taxa), and the high abundance rating applied to *Acacia pendula*. In their recent paper, Tozer and Chalmers (2015) interpreted the results of this ordination as sufficient justification for demarcation of Hunter Valley Weeping Myall Woodland, but we remain cautious on this issue for two reasons:

1. Limitations and context of available data - Numerical classification is only as good as the sample data that goes into it. Hence, if there are limited or questionable data, or even no data within a certain habitat or locality, it is easy to overlook the implications of this when interpreting an analysis. In situations such as Hunter Valley Weeping Myall Woodland, analysis is restricted to what data were available at the time, and the context in which they lie. In 2012, five sample plots were available. Two of these were within a single large and dense stand of *Acacia pendula*, which supported relatively few understorey species, all at low abundance. A third sample was located at a separate but similarly dense stand of *Acacia pendula*, again with a sparse and depauperate understorey. A fourth sample was located within a remnant patch of *Eucalyptus dawsonii* woodland, but with a mid-storey of *Acacia pendula* and various grasses and herbs. The fifth sample was located within derived native grassland in a *Eucalyptus moluccana* landscape, supporting a small group of *Acacia pendula* trees adjacent to a farm watering point. Clearly, a range of different conditions and contexts of Hunter Valley Weeping Myall Woodland were present in this dataset, but all tied by the presence of *Acacia pendula*.
2. Datasets with limited observations – Some environments support few species, and in most cases such as this a single species tends to clearly dominate. Often, this dominance can lead to dense shading which impacts directly on co-occurring species. The formation of dense low forest *Acacia* stands with few other species in other environments is not an uncommon feature of the New South Wales landscape (Keith 2004; Hunter 2005). Even within the Hunter region there are sizeable stands of 'wattle scrubs' dominated by small tree species such as *Acacia binervia, Acacia doratoxylon, Acacia dangarensis,* and *Acacia bulgaensis*. For *Acacia pendula* stands in the Hunter, species diversity is less than half that recorded for surrounding forest and woodland vegetation (mean = 22.6, range 16-33, n = 5 *vs* 46.4, range 18-78, n = 141 from Peake 2006), largely a result of shading. When data from these environments are included in larger datasets where much more diverse environments are typical, seemingly legitimate sample clustering can be achieved in numerical analysis, but these should always be subject to closer scrutiny.

Tozer and Chalmers (2015) used the ordination presented in Bell (2012) to support their case for the existence of Hunter Valley Weeping Myall Woodland, but were likely unaware of the limitations and context of the underlying dataset. To help clarify the situation, we revisited this dataset with the addition of two new samples from purported Hunter Valley Weeping Myall Woodland (identified as such by Umwelt 2013), together with other more recently collected data from various landscapes on Permian sediments of the Hunter Valley, including several sample plots from derived native grasslands. We aimed to delve further into the relationships existing between samples collected within Hunter Valley Weeping Myall Woodland and the surrounding vegetation matrix in which it occurs. To examine the potential influence of low species counts on an analysis (noted in Bell 2012 as a possible reason for sample divergence), we also added four sample plots from an unquestionably foreign habitat that occurs in this part of the Hunter Valley: 20-25 year old mining rehabilitation of Sugar Gum (*Eucalyptus cladocalyx*) forest at Ravensworth (between Singleton and Muswellbrook). Sugar Gum is a South Australian species which was widely planted in the Hunter Valley from the 1970s, and has been used in the rehabilitation of several former mine sites in the region. All plots from the updated dataset are available in the NSW OEH VIS database (http://www.environment.nsw.gov.au/research/Vegetationinformationsystem.htm), and have been sampled by the one observer utilising identical methods (0.04 ha plots, sampling all vascular species, and application of standard 1-6 modified Braun-Blanquet cover abundance codes). Ordination analysis was undertaken in Primer 6 (Clarke & Gorley 2006), using non-metric multi-dimensional scaling, the Bray-Curtis similarity co-efficient and a minimum stress of 0.01.

The revised dataset comprised 402 sample plots from Permian sediments of the central and upper Hunter Valley, extending west along the Goulburn River corridor to Bylong and Wollar (Figure 3), double the samples analysed by Bell (2012). The wide separation of the seven samples from Hunter Valley Weeping Myall Woodland in the ordination (Figure 4) illustrates the variation present in this community, and like the 2012 analysis shows two distinct groups of samples. Crucially, two important points can be highlighted from this analysis that have only become evident with the addition of data from anthropogenic Sugar Gum forest and derived native grasslands. Firstly, the ordination shows how similar some Weeping Myall sites are to the anthropogenic Sugar Gum community (Weeping Myall plots 1-3). These Weeping Myall plots are located at Jerrys Plains cemetery and at Warkworth (both accepted locations for the TEC, and specifically noted in determinations), and they share with *Eucalyptus cladocalyx* stands a very bare and species poor understorey (cf. Figure 5 & 6). In the ordination, these plots fall well clear of the remaining collection of Permian-based forests and woodlands, yet due to their known anthropogenic status they would never be considered representative of an endemic or threatened vegetation community. With no prior knowledge of these data, this outlying group of seven plots (Weeping Myall & Sugar Gum collectively) could very easily be combined and presented as Hunter Valley Weeping Myall Woodland given the divergence it shows from other samples. Although an analysis of similarity would be beneficial to test the significance of such a union, the limited replicates available and the resultant lack of possible permutations restrict this.

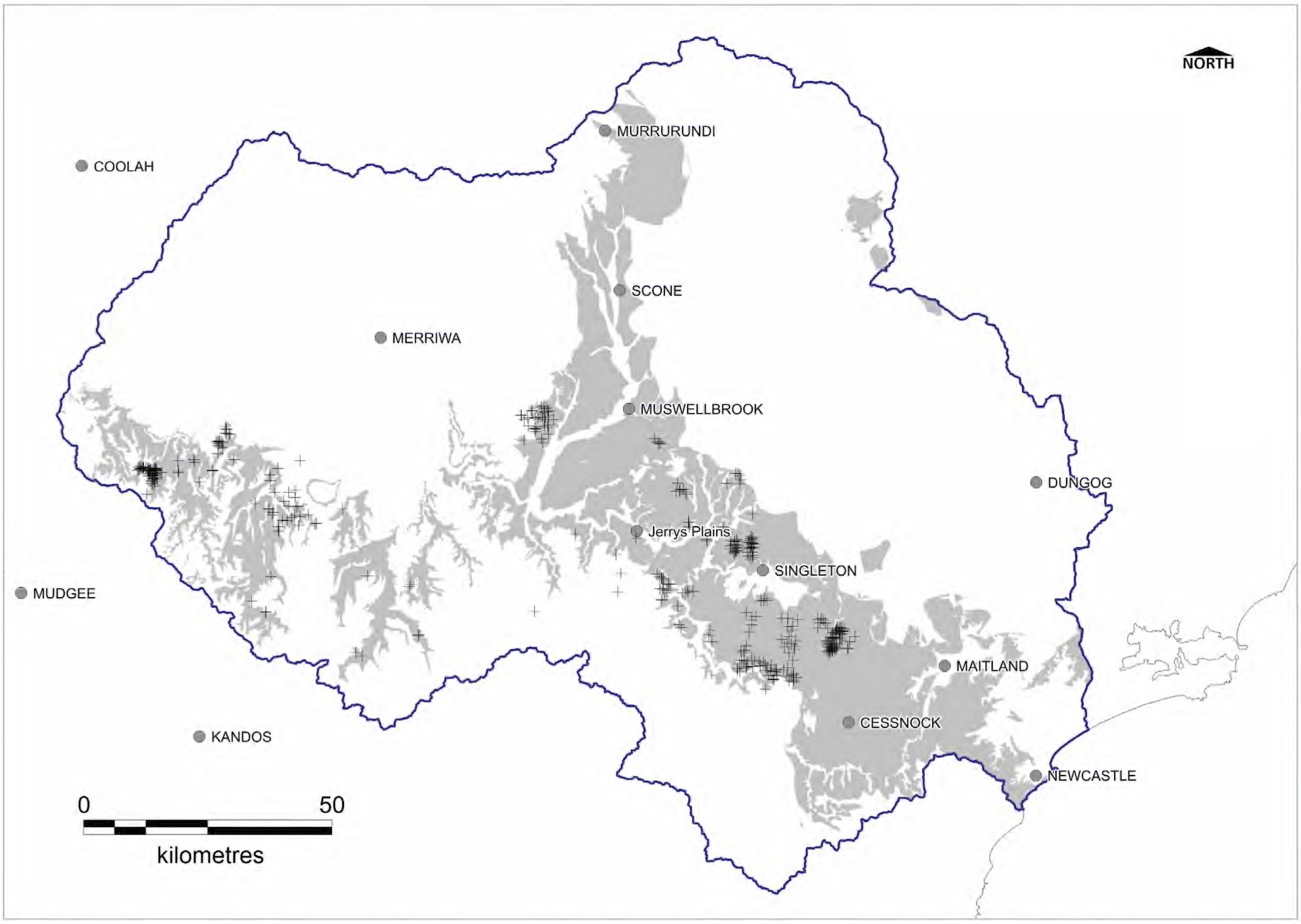

Figure 3. Distribution of 402 sample plots used in ordination analysis, from Permian sediments of the central to upper Hunter Valley, and west along the Goulburn River corridor.

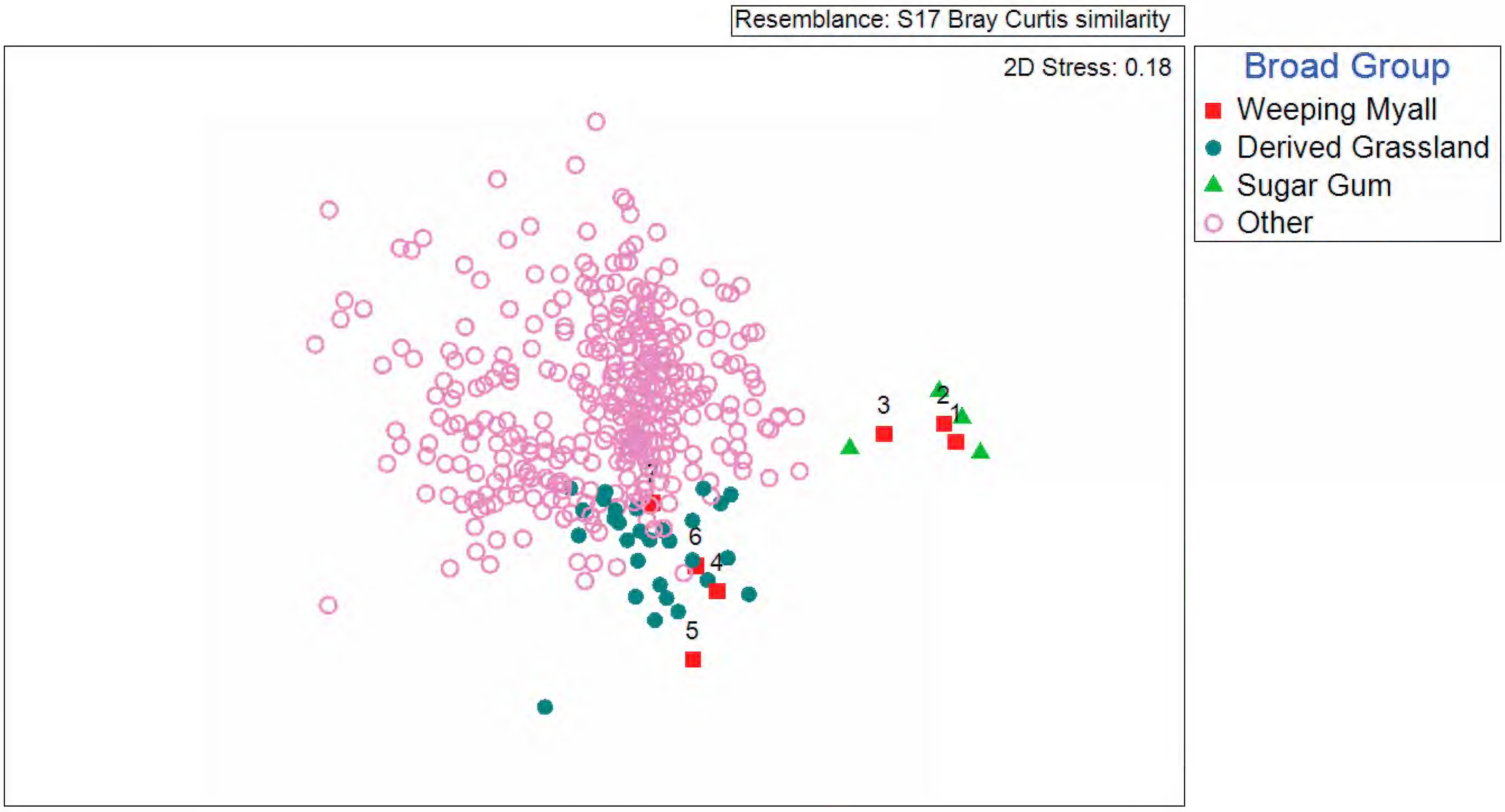

Figure 4. Non-metric multi-dimensional ordination of 402 sample plots from Permian sediments of the Hunter Valley. Plots sampled within Weeping Myall (1-7; 7 obscured), Derived Native Grassland and Sugar Gum are highlighted (*a priori* selected), the balance represent various forests and grassy woodlands on the Hunter Valley floor and footslopes between Cessnock, Muswellbrook and Wollar (approximating the 700 mm annual rainfall isohyet). Weeds removed for analysis; see Appendix 1 for repeat analyses varying key factors.

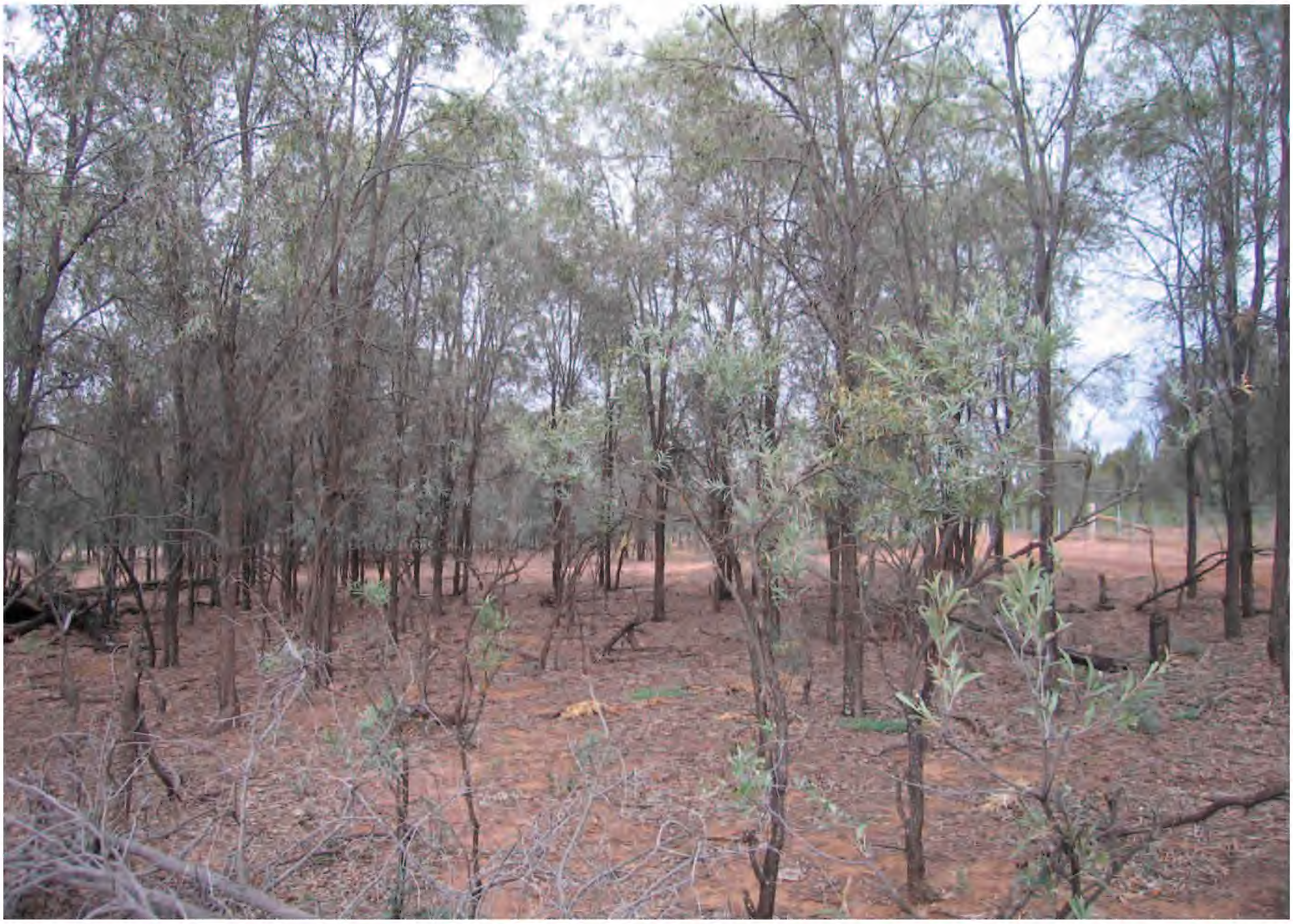

Figure 5. Hunter Valley Weeping Myall Woodland at Warkworth.

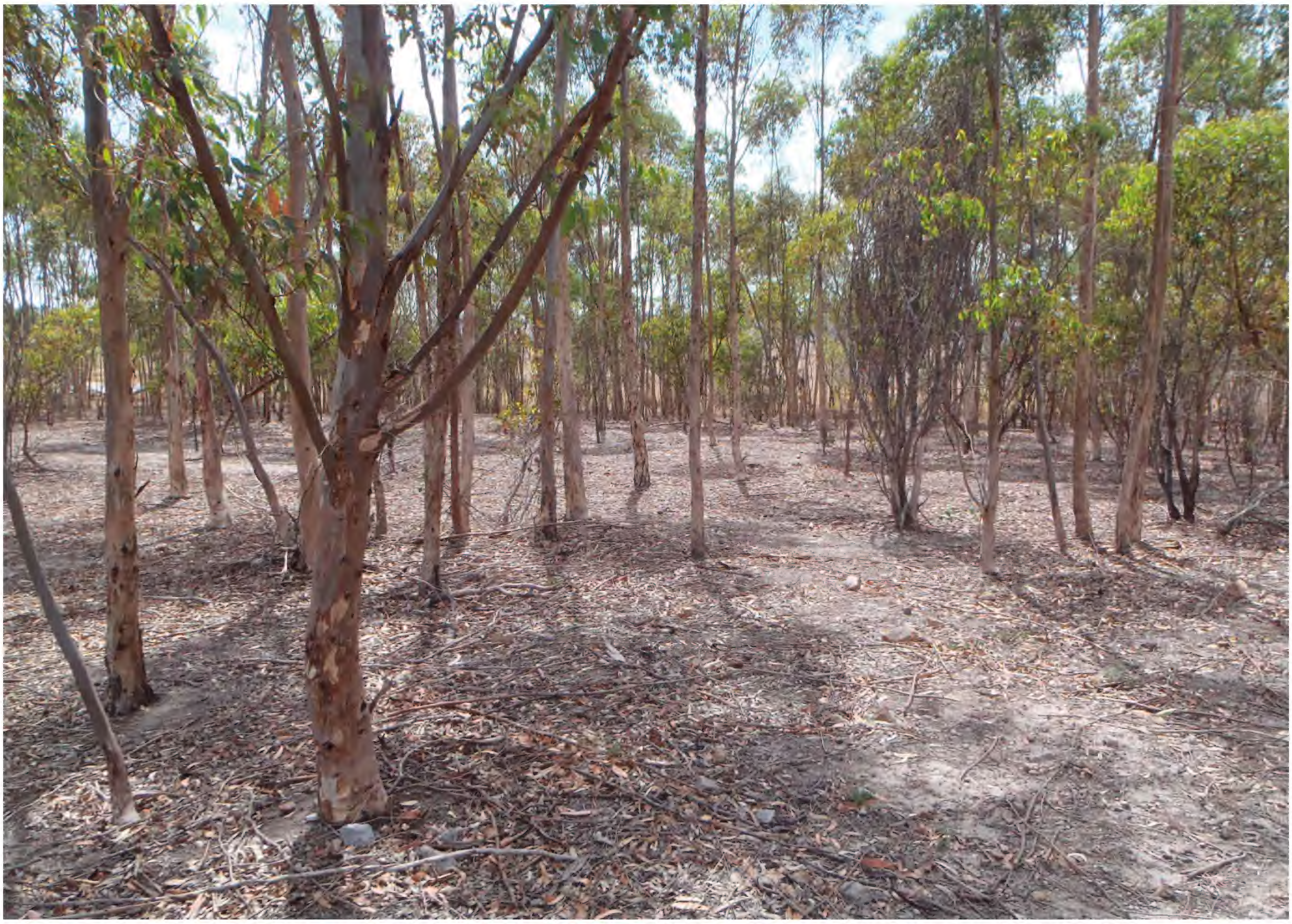

Figure 6. A stand of Sugar Gum (*Eucalyptus cladocalyx*) on mining rehabilitation near Ravensworth.

The ordination also clearly illustrates a strong gradation of Weeping Myall samples from grassy woodland to Derived Grassland (remaining four Weeping Myall plots, 4-7) from the Singleton, Wybong and Warkworth districts. The floristic composition of Weeping Myall plots 4-6 share many species with Derived Grassland, which themselves also merge with other grassy woodlands in the Hunter. Collectively, these three Weeping Myall sites (from the Wybong and Broke localities) are inseparable from the grasslands of the Hunter Valley floor. The final sample (7, also from Broke) is indistinguishable from other grassy woodlands in the Singleton and Broke localities. An analysis of similarity undertaken on these two groups (i.e. Derived Grassland & the grassy form of Weeping Myall), using the ANOSIM routine in Primer, showed there to be no significant difference between them ($R = 0.17$, $p = 0.119$).

The above analysis illustrates the value in a good knowledge of data, and the need to interpret perceived patterns with caution. Repeat analysis including all weed species, and with the masking of *Acacia pendula* returned near-identical results (Figures A1-A3, Appendix 1), suggesting that underlying trends are consistent irrespective of these key variables. Bell (2012) cautioned that the divergence shown in Weeping Myall samples was more likely to be a reflection of the depauperate understorey typical of dense *Acacia* populations, rather than a definable and meaningful group. Tozer and Chalmers (2015) did not concur, but chose to interpret the divergence as representing a valid separation in the data. From the revised ordination produced here, either of the two Weeping Myall groups (Sugar Gum-Weeping Myall or Derived Grassland-Weeping Myall) could, in ignorance, be accepted as Hunter Valley Weeping Myall Woodland, but for the fact that the additional data has highlighted too many inconsistencies in its delineation. Both the Sugar Gum and Weeping Myall samples (samples 1-3 in the ordination) characteristically support a dense small tree layer, over a very poor understorey of similar species. It is not uncommon in numerical analyses for data with relatively few observations in each sample unit to form discrete groups in an ordination or cluster diagram, but it does not always indicate a sensible outcome. Differences may be apparent, but they may be the result of any of a number of unexpected past disturbances. Some authors (e.g. Benson & Ashby 1990) have employed the use of the Kulczynski similarity co-efficient rather than Bray-Curtis to examine disturbed landscapes, as it describes similarity based on shared species composition and not the absence of species. However, there is some evidence to suggest that this co-efficient behaves equally erratically to Bray-Curtis when samples are sparse (Clarke et al. 2006). Despite this, we have utilised this co-efficient in repeat analyses of our dataset, and overall trends remain the same as that presented above (see Figures A4-A6, Appendix 1).

How regional botanists identify Hunter Valley Weeping Myall Woodland

This lack of support for Hunter Valley Weeping Myall Woodland through numerical classifications has confounded attempts by workers in the field to identify this community. As noted earlier, current legislation dictates that a vegetation community be defined using floristic and abiotic characteristics. The *TSC Act 1995*, for example, defines a community as "*an assemblage of species occupying a particular area*". Determinations and listing advices for threatened communities typically provide plant species that characterise a community, which when used in combination with abiotic features identify a particular habitat as that community. Ideally, these lists of species emanate from a numerical classification that can show unequivocal evidence for a community, particularly when placed into context with surrounding or floristically similar assemblages of species. This is yet to be demonstrated for Hunter Valley Weeping Myall Woodland, despite suggestions to the contrary by Tozer and Chalmers (2015).

For some years, regional botanists have highlighted the presence of Hunter Valley Weeping Myall Woodland in development application and other survey work only through the observed presence of *Acacia pendula*: it has become a flagship or *de facto* indicator species for the community. At the extreme, maps of this CEEC have been included in impact assessment reports purely by encircling regrowth stands of *Acacia*, with seemingly little investigation of co-occurring species or landscape position (e.g. Parsons Brinckerhoff 2012; Umwelt 2013). In other cases attempts have been made to rationalise field data with legal descriptions (e.g. FloraSearch 2014), but a conservative viewpoint has often been adopted. In the absence of more tangible guidelines, investigations such as these are good examples of how the presence of stands of *Acacia pendula* have been used as a surrogate for identifying Hunter Valley Weeping Myall Woodland. Indeed, there are no examples of habitat being mapped as Hunter Valley Weeping Myall Woodland in the absence of *Acacia pendula*. Such a situation is undesirable in threatened species planning, where competition for conservation dollars in an already congested field may impact on other more deserving species or communities.

Conclusions

In our earlier paper (Bell & Driscoll 2014a), we outlined several reasons in support of *Acacia pendula* never having been a natural component of the landscape in the Hunter Valley prior to European settlement. This included an extensive search of historical and contemporary literature, review of database and herbarium records, and an assessment of habitat both within and outside of the Hunter Valley. Our argument was acknowledged as persuasive by Tozer and Chalmers (2015), but they consequently suggested that uncertainty regarding the origins of this species did not necessarily preclude the existence of Hunter Valley Weeping Myall Woodland, and the other semi-arid species apparently associated with it.

From the information presented here, Hunter Valley Weeping Myall Woodland, as a definable ecological community, is indefensible with and without the presence of *Acacia pendula*. Purported associations of this CEEC with a small number of western species, and their presence in the Hunter facilitated by a Goulburn Valley movement corridor, are difficult to support. Of the seven key species discussed by Tozer and Chalmers (2015), most have been shown here to be widespread in the Hunter, and are associated with a range of other ecosystems across the Hunter Valley floor between Cessnock, Muswellbrook and Sandy Hollow. These species are not restricted to, or most commonly found in, Hunter Valley Weeping Myall Woodland, but form a component of several other ecosystems across the landscape. Further, these species have been shown in recent surveys to also extend beyond the Sandy Hollow truncation suggested by Tozer and Chalmers (2015), and into the Bylong Valley and other catchments of the Goulburn River around Wollar; there is a consistent presence of many of these species extending east from western districts, which perhaps was not evident in previous collections or records. Across those lands *Acacia pendula*, or a community associated with it, does not form part of the current-day landscape, and there is little evidence to suggest it ever was.

There is indeed some merit in the theory that the dispersal of plant propagules from the west via this Goulburn Valley corridor has occurred in the past. However, this easterly movement of species should not be used in support of a threatened ecosystem that cannot be defined on the ground, and where there is still debate over whether its main and structurally domineering member naturally occurs in the Hunter. Despite the presence of these westerly species in the Hunter, and there are many, anthropogenic disturbances in the 200 years of European settlement have surely blurred the boundaries of any ecosystem that may have once had merit in protecting. Tozer and Chalmers (2015) themselves noted that "*… the long history of disturbance in the Hunter Valley, combined with a paucity of systematic, quantitative survey data, increases the risk that biogeographic patterns are confounded with anthropogenic artefacts*". In short, there is no current-day evidence to suggest that these western species can be used as a surrogate for, or indication of, Hunter Valley Weeping Myall Woodland. More realistically, these species form a part of the dominant grassy woodlands of the Hunter Valley floor, habitats which are already represented in the State listed Central Hunter Grey Box – Ironbark Woodland, Central Hunter Ironbark – Spotted Gum – Grey Box Forest, Hunter Valley Footslopes Slaty Gum Woodland, and grasslands derived from these, and the federally listed Central Hunter Valley Eucalypt Forest and Woodland.

If such a suite of western species indicative of Hunter Valley Weeping Myall Woodland cannot be identified by species association, can it be defined using numerical classification techniques? The revised ordination presented in this paper, based on over 400 sample sites across Permian sediments from the central and upper Hunter, shows conclusively that it cannot. Samples representative of the two forms of Hunter Valley Weeping Myall Woodland are floristically no different from anthropogenic stands of *Eucalyptus cladocalyx* on old mining land, and native grasslands derived from *Eucalyptus crebra* and/or *Eucalyptus moluccana* landscapes. The divergence in data observed in the earlier ordination presented in Bell (2012) was evidently a function of data availability and context, which cannot be maintained when tested with additional data from these two habitats. Suggestions in that earlier work that shading by dense *Acacia* stands may be creating an unnatural grouping in the ordination, and that a cautious interpretation be made, have been justified here. There remains a lack of satisfactory and conclusive numerical support for the delineation of Hunter Valley Weeping Myall Woodland.

In our view, there is no justification for the listing of Hunter Valley Weeping Myall Woodland as a Critically Endangered Ecological Community at either State or Federal level. Further, with the uncertainty surrounding the origins of Hunter *Acacia pendula* plants, uncertainty which Tozer and Chalmers (2015) acknowledge, there is no justification for any endangered community or population listing related to this species. The distribution of multiple western species in relation to soil and climatic gradients in the Hunter occurs irrespective of, and in no relationship to, Hunter Valley Weeping Myall Woodland. Consequently, we disagree that the origin of *Acacia pendula* is irrelevant to the status of Hunter Valley Weeping Myall Woodland, as with or without this species there is no support for a community. We see little gain in legally protecting an entity at the highest possible threat category, both under Commonwealth and New South Wales legislation, when experienced and competent botanists cannot confidently locate it in the field without the visual cue of *Acacia pendula*, and when co-occurring species in those stands differ imperceptibly from the surrounding landscape.

Acknowledgements

Floristic data used in analyses in this paper has been collected during numerous projects for both government and private clients over many years, and its use is gratefully acknowledged. Thanks also to Tim Curran and John Neldner for helpful comments on an earlier version of this paper.

References

Beadle NCW (1981) *The Vegetation of Australia*. Cambridge University Press, Cambridge.

Bell, S.A.J. (2007) Acacia pendula *in the Hunter Valley: Update of investigations*. Unpublished Report to HLA Envirosciences Pty Ltd & Wambo Coal Mine. Eastcoast Flora Survey. June 2007.

Bell, S. (2012) Consultancy advice regarding a review of the 2005 listing under the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act) of *Weeping Myall – Coobah – Scrub Wilga Woodland/Low Forest of the Hunter Valley*, for Department of Sustainability, Environment, Water, Population and Communities, Canberra.

Bell, S. and Driscoll, C. (2014a) *Acacia pendula* (Weeping Myall) in the Hunter Valley of New South Wales: early explorers' journals, database records and habitat assessments raise doubts over naturally occurring populations. *Cunninghamia* 14: 179–200.

Bell, S.A.J. & Driscoll, C (2014b) *Assessment and mapping of vegetation in the Bylong Valley: Authorisations 287 & 342.* Unpublished Final Report to Hansen Bailey Pty Ltd. Eastcoast Flora Survey. December 2014.

Benson, J.S. & Ashby, E.M (2000) Vegetation of the Guyra 1: 100 000 map sheet New England Bioregion, New South Wales. *Cunninghamia* 6(3): 747-872.

Clarke, K.R. & Gorley, R.N. (2006) *PRIMER v6: User Manual/ Tutorial*. PRIMER-E: Plymouth.

Clarke, K.R., Somerfield, P.J., & Chapman, M.G. (2006) On resemblance measures for ecological studies, including taxonomic dissimilarities and a zero-adjusted Bray-Curtis coefficient for denuded assemblages. *Journal of Experimental Marine Biology and Ecology* 330: 55-80.

Ecovision (2008) *Ecological Impact Assessment – Stage 2 of the Moolarben Coal Project*. Unpublished Report to Moolarben Coal.

FloraSearch (2005) *Wilpinjong Coal Project. Appendix HA: Flora Assessment*. Unpublished Report to Wilpinjong Coal.

FloraSearch (2014) *North Wambo Underground – Longwall 10A Modification. Flora Assessment.* Prepared for Wambo Coal Pty Limited by FloraSearch, August 2014.

Keith, D.A. (2004) *Ocean Shores to Desert Dunes: The Native Vegetation of New South Wales and the ACT.* Department of Environment and Conservation: Hurstville.

Hunter, J.T. (2005) Floristics and distribution of Wattle Dry Sclerophyll Forests and Scrubs in north-eastern New South Wales. *Cunninghamia* 9(2): 317-323.

Moolarben Biota (2006) *Moolarben Coal Project Flora, Fauna and Aquatic Ecology Assessment.* Unpublished Report to Moolarben Coal.

NSW Scientific Committee (2006) *Final Determination to list Hunter Valley Weeping Myall Woodland of the Sydney Basin Bioregion as an endangered ecological community*. NSW Scientific Committee.

NSW Scientific Committee (2016) *Final Determination to list Hunter Valley Weeping Myall Woodland of the Sydney Basin Bioregion as a critically endangered ecological community*. NSW Scientific Committee.

Parsons Brinckerhoff (2012) *Doyles Creek underground mine and training school. Project overview*. NuCoal Resources Ltd, March 2012.

Peake, T.C. (2006) *The Vegetation of the Central Hunter Valley, New South Wales. A report on the findings of the Hunter Remnant Vegetation Project*. Hunter–Central Rivers Catchment Management Authority, Paterson.

Sivertsen, D., Roff, A., Somerville, M., Thonell, J., & Denholm, B. (2011) *Hunter Native Vegetation Mapping. Geodatabase Guide (Version 4.0).* Internal Report for the Office of Environment and Heritage, Department of Premier and Cabinet, Sydney, Australia.

Somerville, M. (2009) *Hunter, Central & Lower North Coast Vegetation Classification & Mapping Project. Volumes 1: Vegetation classification technical report*. Prepared by HCCREMS/ Hunter Councils Environment Division for Hunter-Central Rivers Catchment Management Authority, Tocal, NSW.

Tozer, M., & Chalmers, A. (2015) Should Hunter Valley Weeping Myall Woodland in the Sydney Basin Bioregion be listed as a Threatened Ecological Community? *Cunninghamia* 15: 201-204.

Umwelt (Australia) Pty Limited (2006) *Status of the Endangered Ecological Community, Hunter Valley Weeping Myall Woodland*. Prepared by Umwelt (Australia) Pty Limited for the Department of Environment and Conservation (NSW).

Umwelt (Australia) Pty Limited (2013) *Ecological Impact Assessment: Bulga Optimisation Project.* Prepared by Umwelt (Australia) Pty Limited on behalf of Bulga Coal Management Pty Limited, April 2013.

Wells Environmental Services (2011) *Mt Penny Coal Project. Preliminary Environmental Assessment*. Unpublished Report, February 2011.

Manuscript accepted 13 May 2016

Appendix 1 Repeat analyses varying weed presence, inclusion of *Acacia pendula* and *Acacia melvillei*, and similarity coefficient (Bray-Curtis vs Kulczynski).

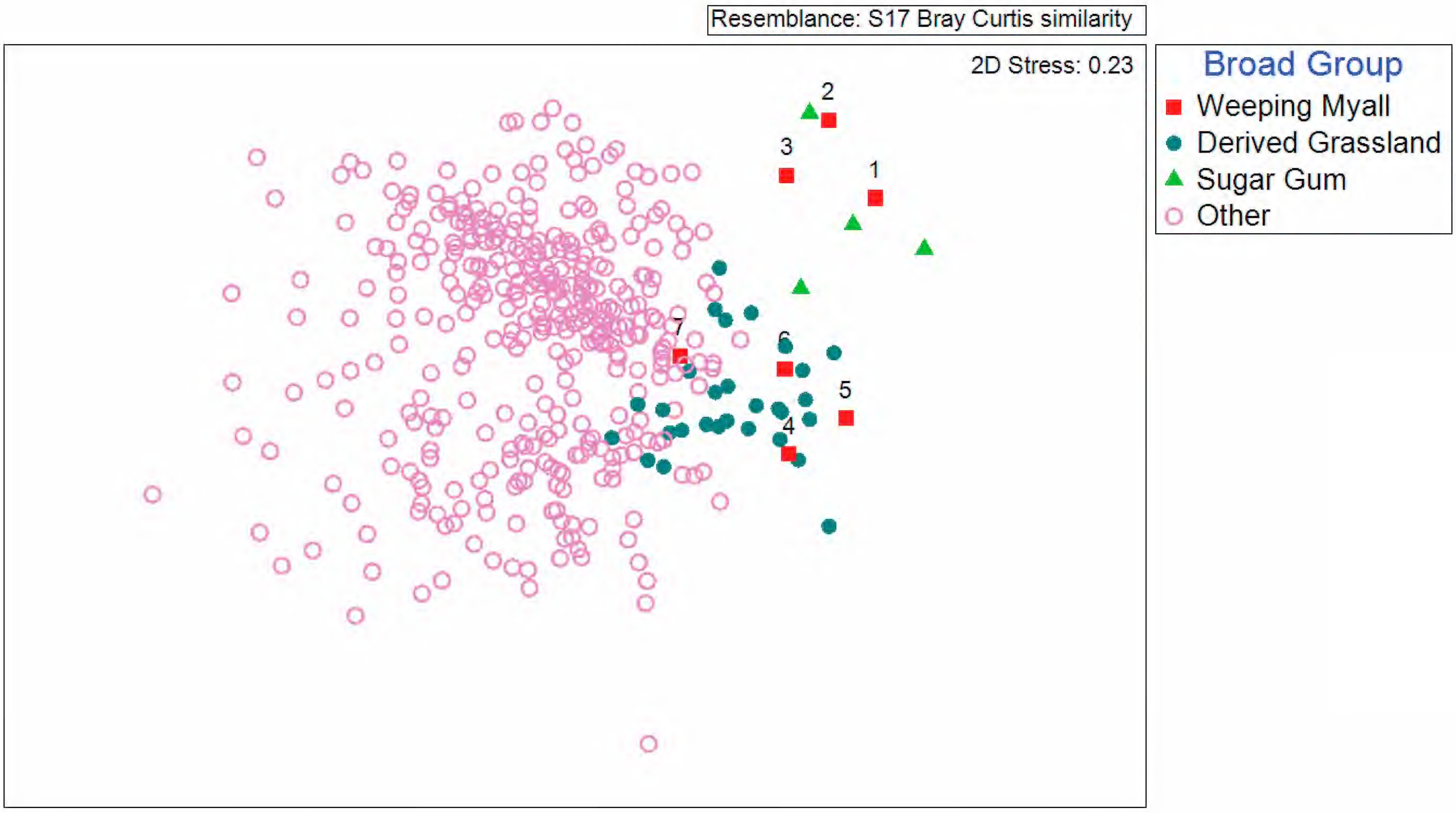

Figure A1. Non-metric multi-dimensional ordination of 402 sample plots from Permian sediments of the Hunter Valley. Plots sampled within Weeping Myall (1-7; 7 obscured), Derived Native Grassland and Sugar Gum are highlighted (*a priori* selected). **Bray-Curtis similarity index. Weeds included in analysis.**

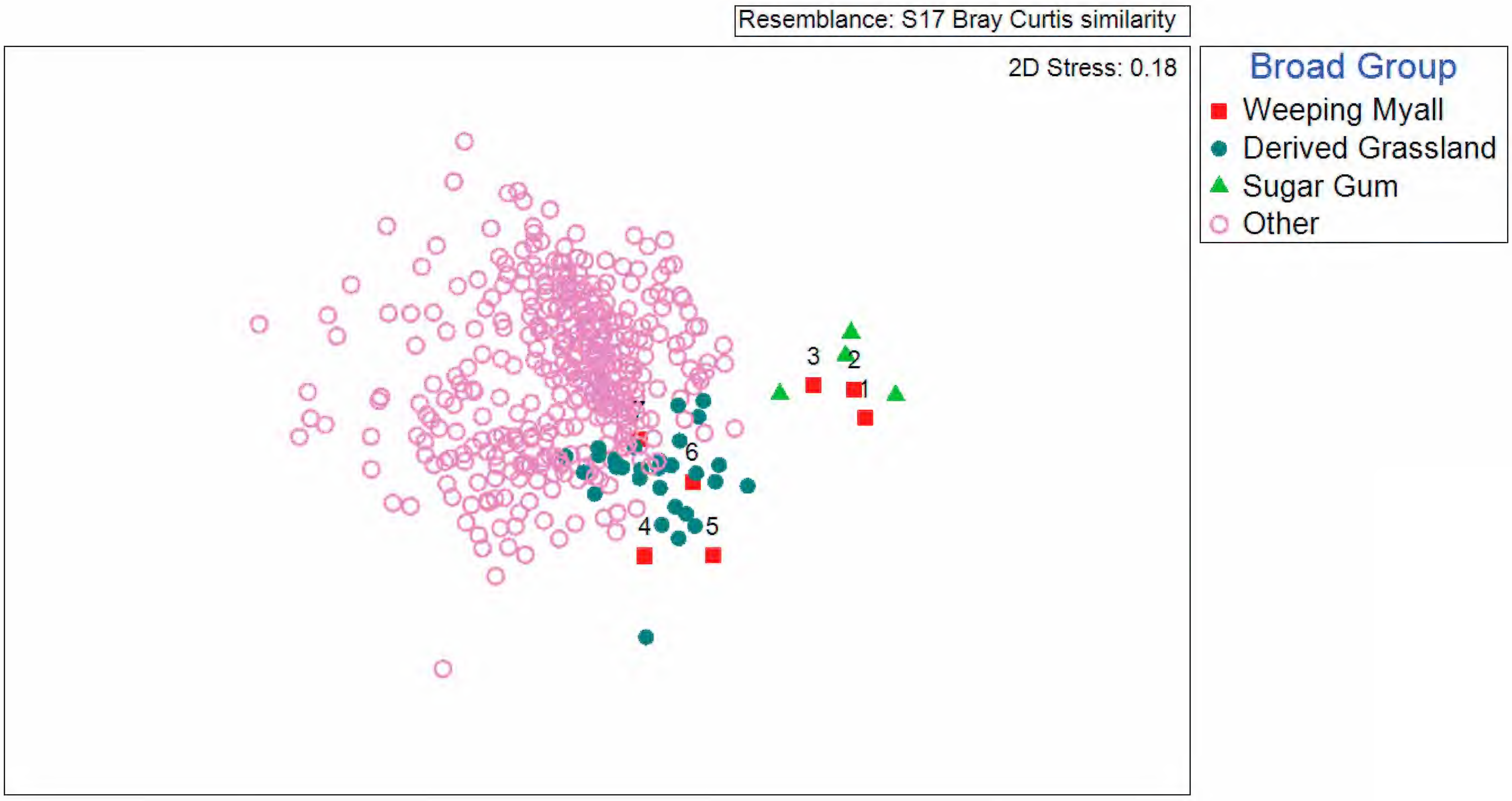

Figure A2. Non-metric multi-dimensional ordination of 402 sample plots from Permian sediments of the Hunter Valley. Plots sampled within Weeping Myall (1-7; 7 obscured), Derived Native Grassland and Sugar Gum are highlighted (*a priori* selected). **Bray-Curtis similarity index. Weeds, *Acacia pendula* and *Acacia melvillei* excluded from analysis.**

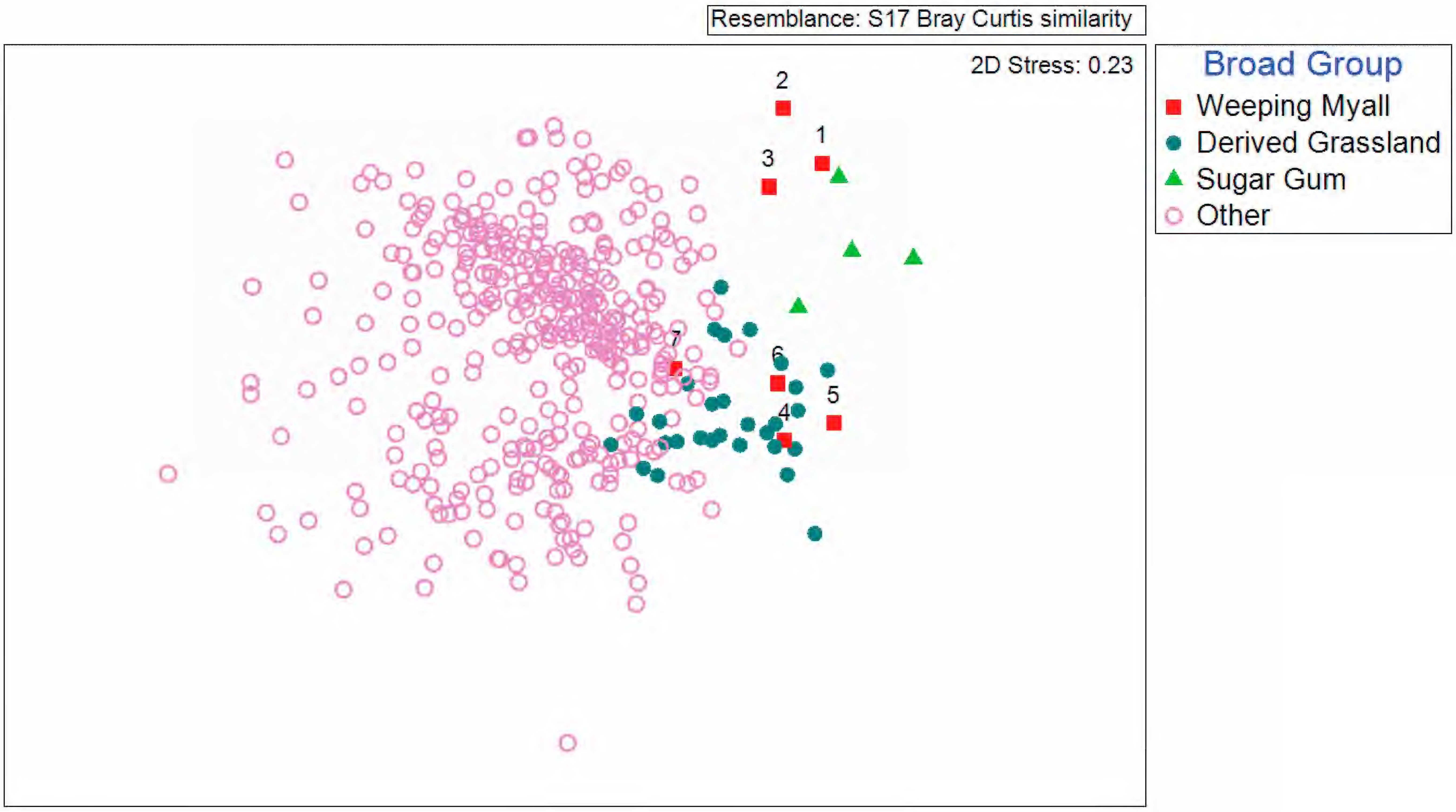

Figure A3. Non-metric multi-dimensional ordination of 402 sample plots from Permian sediments of the Hunter Valley. Plots sampled within Weeping Myall (1-7; 7 obscured), Derived Native Grassland and Sugar Gum are highlighted (*a priori* selected). **Bray-Curtis similarity index. Weeds included but *Acacia pendula* and *Acacia melvillei* excluded from analysis.**

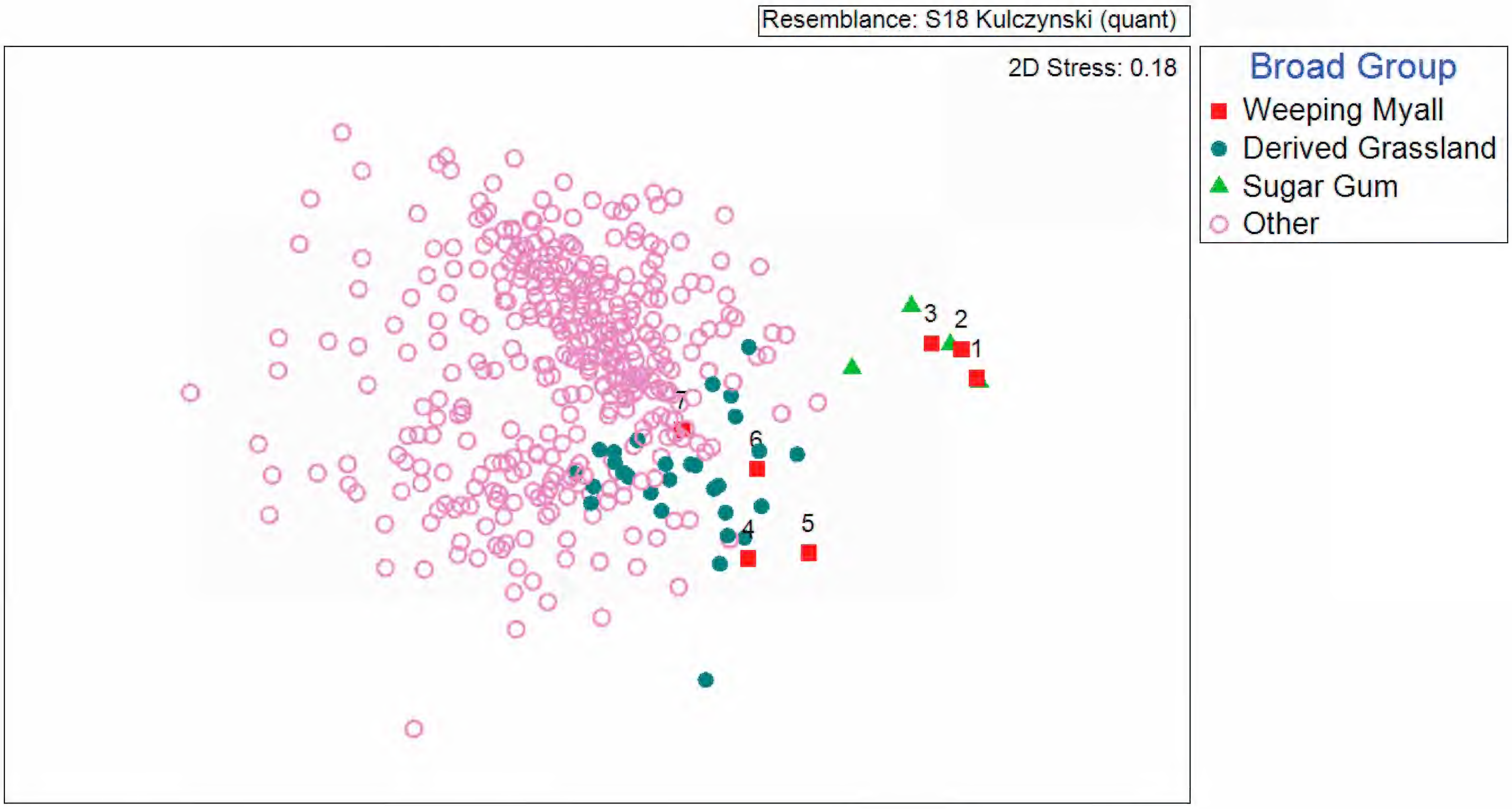

Figure A4. Non-metric multi-dimensional ordination of 402 sample plots from Permian sediments of the Hunter Valley. Plots sampled within Weeping Myall (1-7; 7 obscured), Derived Native Grassland and Sugar Gum are highlighted (*a priori* selected). **Kulczynski similarity index. Weeds excluded from analysis**.

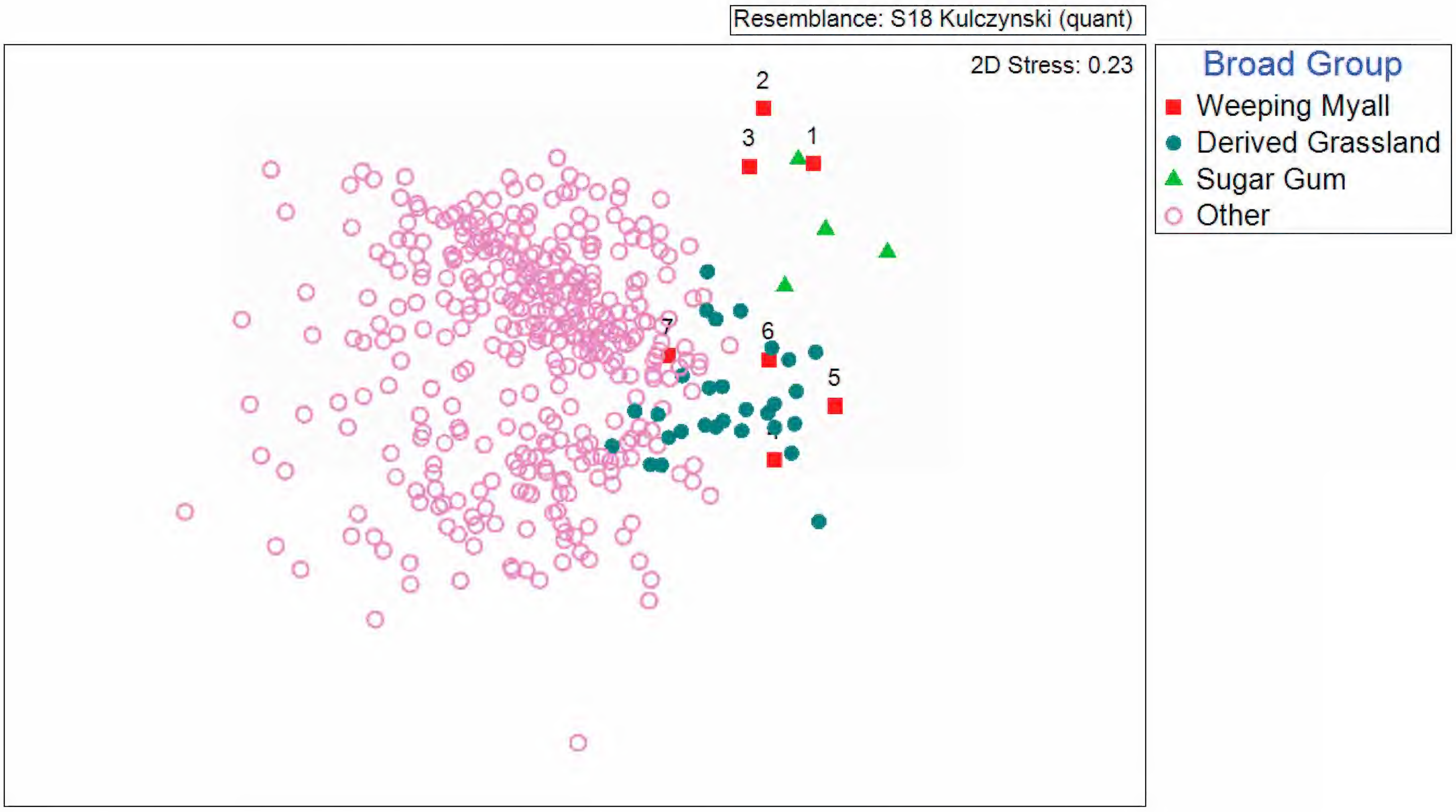

Figure A5. Non-metric multi-dimensional ordination of 402 sample plots from Permian sediments of the Hunter Valley. Plots sampled within Weeping Myall (1-7; 7 obscured), Derived Native Grassland and Sugar Gum are highlighted (*a priori* selected). **Kulczynski similarity index. Weeds included in analysis.**

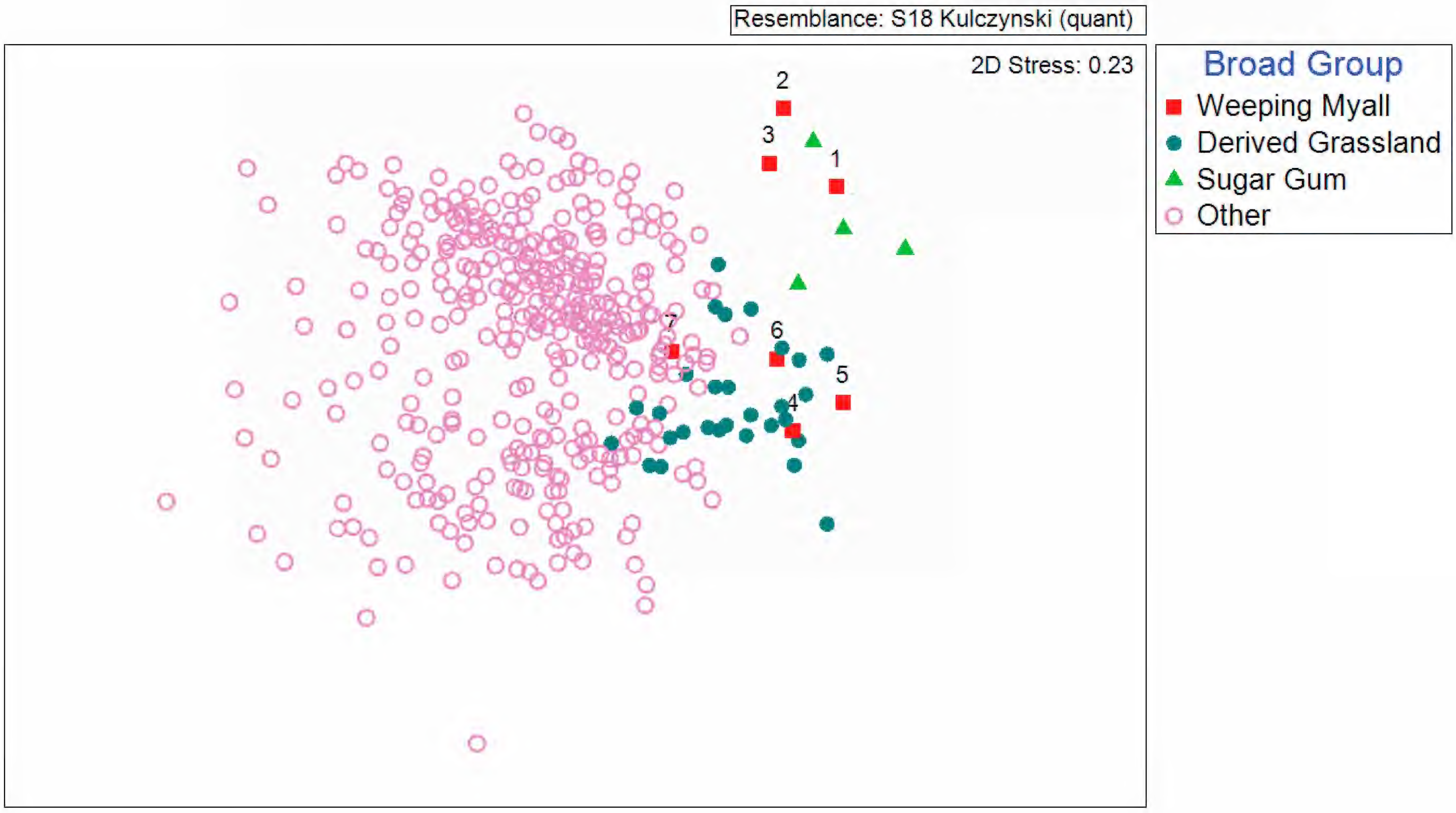

Figure A6. Non-metric multi-dimensional ordination of 402 sample plots from Permian sediments of the Hunter Valley. Plots sampled within Weeping Myall (1-7; 7 obscured), Derived Native Grassland and Sugar Gum are highlighted (*a priori* selected). **Kulczynski similarity index. Weeds, *Acacia pendula* and *Acacia melvillei* excluded from analysis.**

Cunninghamia
A journal of plant ecology for eastern Australia

Date of Publication:
July 2016

The Royal
Botanic Garden
Sydney

ISSN 0727-9620 (print) • ISSN 2200-405X (Online)

Hunter Valley Weeping Myall Woodland in the Sydney Basin Bioregion should remain listed as a Threatened Ecological Community until strong evidence emerges in support of delisting.

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***Cunninghamia* (2016): 31-34**
doi 10.7751/cunninghamia.2016.16.004

Determinations for the listing of Ecological Communities made under the NSW *Threatened Species Conservation (TSC) Act (1995)* draw on the best information available at the time of listing. These data may either be qualitative or quantitative, and with or without analytical evaluation. Periodic reappraisal of the definition or status of a community may therefore be required as new data or analyses become available. In this respect, the contributions of Bell and Driscoll (2014, 2016) constitute a commendable commitment to the application of quantitative survey data to the question of how (or if) the Hunter Valley Weeping Myall Woodland should be defined.

In our response to their proposition that *Acacia pendula* was introduced to the Hunter Valley following European settlement (Tozer and Chalmers 2015), we argued that: i) the definition of a community should not be based on the presence of an individual species; and ii) irrespective of the status of *Acacia pendula,* there is evidence to support the definition of Hunter Valley Weeping Myall Woodland as an assemblage characterised by semi-arid species occupying hot and dry parts of the Hunter Valley. We believe that there are several weaknesses in the counter-arguments presented by Bell and Driscoll (2016). We outline these below before briefly elaborating on how the ordination of floristic data may be used to progress toward a more refined understanding of the composition and distribution of this Critically Endangered Community.

Bell and Driscoll (2016) contend that the assemblage of species listed in the Final Determination does not constitute a valid definition of Hunter Valley Weeping Myall Woodland because the species are widespread in a range of communities and thus show no fidelity to the community as listed. We concede that in the absence of a set of quantitative data sampled across the range and extent of the community, the nominated list of species is unlikely to be both optimal and comprehensive, and can be expected to evolve as suitable data become available. We point out, however, that the existence of such a sample is a prerequisite to the determination of fidelity, and thus the lack of fidelity alluded to by Bell and Driscoll (2016) is asserted rather than demonstrated.

More importantly, their argument suggests a misunderstanding of the community concept as currently applied to vegetation classification. The contemporary application is informed by a continuum model, under which species are understood to vary in abundance along environmental gradients with some degree of independence (Begon *et al*. 2006). As a consequence of this:

- communities are expected to exhibit variability in the assemblage of species present in different locations,
- boundaries between different communities are likely to be vague,
- there is likely to be much overlap in the species membership between different communities, and
- communities can rarely be identified conclusively based on their dominant species alone.

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Bell and Driscoll's (2016) evidence for the distribution of semi-arid species across a range of vegetation communities in the central and upper Hunter Valley is therefore inconclusive. A species need not be either diagnostic of, or faithful to, a community in order to be a characteristic member, and it is widely understood that species listed in Determinations of Threatened Ecological Communities frequently occur in other communities as well. Our characterisation of the Hunter Weeping Myall Woodland implicitly incorporates the notion that semi-arid species are distributed on a gradient of moisture supply, and that they decrease in abundance from west to east due to factors such as physiological constraints and competition from other species. From this perspective, the key question is not how widely distributed individual species are, but how they co-occur in recognisable patterns along ecological gradients. We assume that the response optima of different species will vary along the hypothesised moisture gradient, and that species rarely occupy the full extent of their fundamental niches as a consequence of interactions with other species, disturbance regimes and other factors (Weins *et al*. 2009).

The logical progression from our characterisation of Hunter Valley Weeping Myall Woodland is the acquisition of data appropriate for a closer scrutiny of patterns of species turnover along climatic gradients in the central and upper Hunter Valley. Evidence in support of the continued listing of the community would comprise a more precise characterisation of the niche it occupies and the way in which the particular assemblage of species differs from others in the area. Alternatively, such evidence may not be found, in which case the argument for continued listing would be weakened and alternative vegetation classifications and possible listings could be considered.

From this perspective, the ordination analyses of Bell and Driscoll (2016) do little to advance arguments either for or against the recognition of Hunter Valley Weeping Myall Woodland, because they rely on the assumption that the sites in which *Acacia pendula* occurs constitute a sample of the putative assemblage. This stance is dependent on an extensional definition of the community and is inflexible to the proposition that the community forms part of a continuum in response to a moisture/temperature gradient. It is also inconsistent with their view that the populations of *Acacia pendula* in the Hunter Valley are not natural. Their assertion that "*community types identified in the field provide a better indication of exactly where the target species occur in the landscape, and have not been compromised to accommodate a broader classification*" suggests they favour an approach to community classification constrained by dominant species. We emphasise that dominant species are not a reliable basis for the classification and identification of community type under a continuum model.

The limitations imposed when community membership is assumed *a priori* by reference to structure or dominant species are illustrated by Bell and Driscoll's (2016) interpretation of the overlap in species composition between four sites dominated by *Acacia pendula* and sites sampling derived grassland (native vegetation from which the trees have been removed). They argue that Hunter Valley Weeping Myall Woodland is not a unique assemblage because there is no difference in average similarity among sites sampling *Acacia pendula* or derived grasslands. This assumes that sites sampling grasslands and those sampling Acacia pendula are not part of the same assemblage on the basis of the presence or absence of a singe species. We argue that an alternative interpretation deserves scrutiny: that those sites (both eucalypt woodland and derived grassland) clustering closely with sites dominated by *Acacia pendula* have in common a suite of species by virtue of the physical characteristics shared by the locations in which they occur.

A resolution of this argument requires that the evidence for any anthropogenic effects be weighed against the potential influence of ecological drivers via a gradient analysis. For example, the ordination diagrams presented by Bell and Driscoll (2016) do not show a distinct cluster representing a combination of derived grassland and *Acacia pendula* sites. Rather, they show a continuum along which there is extensive overlap among the three categories of woodland and grassland. The extent to which this pattern constitutes evidence for the recognition of Hunter Valley Weeping Myall Woodland depends on the degree to which it correlates with plausible ecological drivers and is manifested in response gradients in individual species.

While we do not have access to the full data analysed by Bell and Driscoll (2016) we illustrate the first steps of such an approach in Figure 1. Figure 1a shows that the two sites sampling stands of *Acacia pendula* (those we had at our disposal) lie at one end of a compositional gradient that correlates with gradients in primary productivity, water deficit and extremes in summer temperature maxima. Compositionally, therefore, these sites plausibly represent the end point of a pattern in the distribution of species (and hence the composition of communities) between the coast and the hottest and driest parts of the valley. This environmental space is also sampled by a subset of sites representing other communities (as interpreted by Sivertsen *et al*. 2011) (Figure 1b). However, the full set of samples for these communities (MU085, MU086, MU173) is more broadly distributed in environmental space, including areas with lower summer maxima and lower water deficit (Figure 1b). All samples located in the relatively restricted areas of the Hunter valley that experience the most extreme drought conditions (Figure 1c) are candidates for reassessment as a sample of Hunter Weeping Myall Woodland.

We emphasise that this result is merely indicative of an ecological (as apposed to anthropogenic) pattern and does not constitute a comprehensive analysis of all the available survey data. It supports the concept of the Hunter Valley Weeping Myall Woodland as we have interpreted it, but reinforces the need to acquire more field data as a precursor to defining an appropriate sample set upon which to refine the classification.

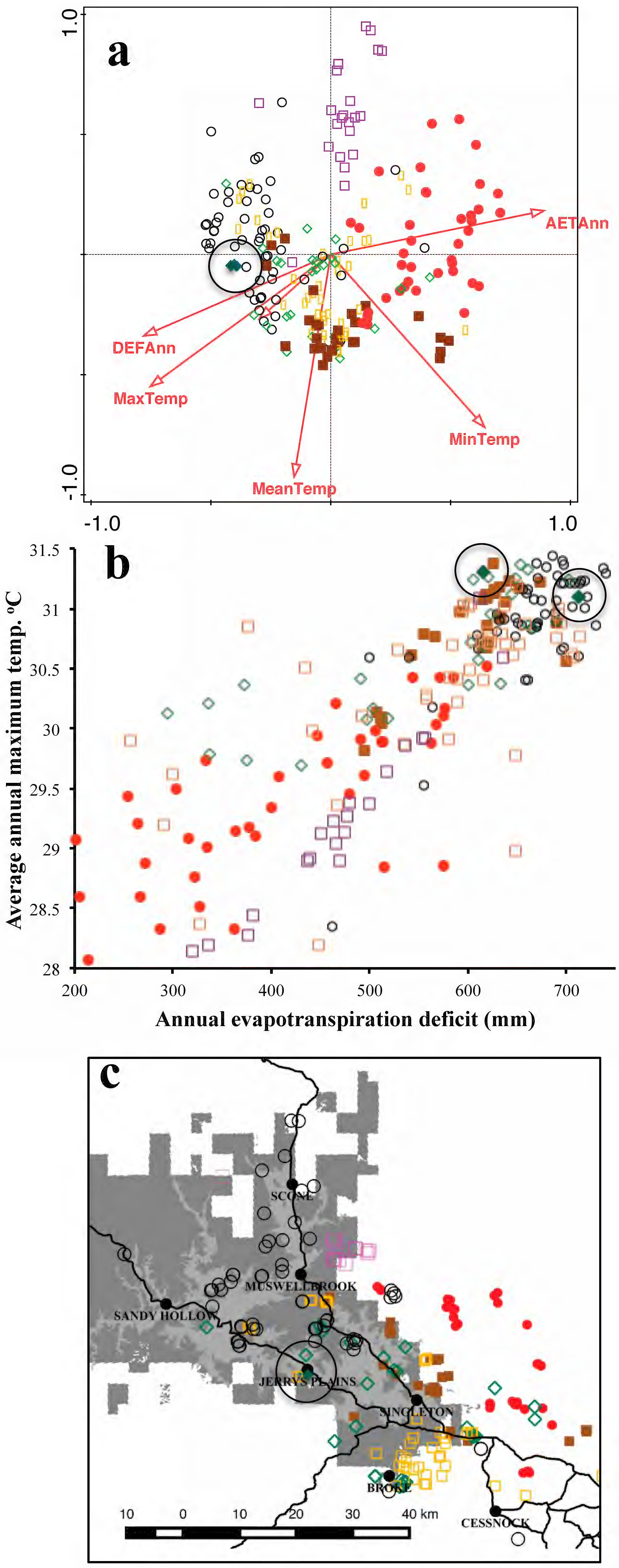

Figure 1: a) Ordination of survey samples representing major vegetation communities occurring on Permian sediments in the central and upper Hunter Valley. Community classes are as defined by Sivertsen *et al*. (2011) and differentiated by symbols as described below. Sample data were analysed by canonical correspondence analysis assuming unimodal species response curves and projected in two dimensions using biplot scaling. Arrows indicate the direction of increase in environmental variables in the ordination space and their lengths are proportional to the magnitude of change. The large black circles indicate the locations of two sites sampling vegetation dominated by *A. pendula*. AETAnn and DEFAnn represent total annual evapotranspiration and evapotranspiration deficit calculated by compiling a water balance model in a spatial framework using a Geographic Information System (Stephenson 1990, Dyer 2009). Temperature data are average annual maximum, minimum and mean supplied as raster layers by the Bureau of Meteorology (http://www.bom.gov.au/climate/averages/climatology/gridded-data-info/gridded-climate-data.shtml).

b) Location of the samples depicted in a) in environmental space as represented by the size of the annual evapotranspiration deficit and the average annual maximum temperature. Symbols are as described below.

c) Extent of area in the Hunter Valley in which the annual evapotranspiration deficit exceeds 600 mm (dark grey). The subset of this area over which the average maximum temperature exceeds 31.25°C is overlaid in light grey and is indicative of the envelope in which Hunter Weeping Myall Woodland potentially occurs.

(◆ - MU026 Weeping Myall/ Cooba/ Wilga shrubland of the Hunter Valley, ■- MU083 Spotted Gum/ Narrow-leaved Ironbark / Red Ironbark shrub/ grass open forest of the central and lower Hunter, ● - MU084 Spotted Gum/ Narrow-leaved Ironbark shrub/ grass open forest of the central and lower Hunter Valley, ◇ - MU085 Narrow-leaved Ironbark/ Bull Oak/ Grey Box shrub/ grass open forest of the central and lower Hunter, □ - MU086 Narrow-leaved Ironbark/ Grey Box/ Spotted Gum shrub/ grass open forest of the central and lower Hunter, □ - MU088 White Box/ Narrow-leaved Ironbark/ Blakely's Red Gum shrubby open forest of the central and upper Hunter O - MU173 Narrow-leaved Ironbark/ Grey Box grassy woodland of the central and upper Hunter).

We concede that we may have confused the issue by stating that the current distribution of *Acacia pendula* is a better approximation of the distribution of the community than any other available proxy. By this we meant the extent of its present occurrence between the locations of Broke, Singleton, Muswellbrook and Sandy Hollow rather than the location of individual stands. Nevertheless, we did not, as Bell and Driscoll (2016) claim, draw any inference from the distribution of Weeping Myall sites in the ordination diagrams of Bell (2012). We simply reported these findings and Bell's interpretation that the most parsimonious explanation for the separation of Weeping Myall sites from others in the dataset was the depauperate understory of those sites. That being the case, the subsequent analyses of Bell and Driscoll (2016) lead only to the trivial conclusion that dense stands of *Acacia pendula* with a depauperate understory are most similar to other monospecific stands with depauperate understory. The key question of whether the hottest and driest parts of the Hunter Valley support an assemblage of species that differs significantly from other parts of the Hunter Valley remains unanswered.

Nominations for Threatened Ecological Communities derive from a range of sources and are supported by observations and data with different strengths and weaknesses. Inevitably, experienced ecologists will disagree on the merits of a particular nomination, and it is in this context that the Scientific Committee must weigh the uncertainty with respect to how a community can be defined against the risk of an adverse outcome should it fail to be listed. While the current Determination may not be the best possible characterisation of Hunter Valley Weeping Myall Woodland, Bell and Driscoll's (2016) observation that 200 years of European settlement may well have blurred any putative assemblage of semi-arid species beyond recognition suggests that a Critically Endangered Listing is indeed warranted.

Acknowledgements

We gratefully acknowledge the contributions of Isaac Jansens and Christopher Simpson to data analysis and for constructive criticism of an earlier version of the manuscript.

References

Begon, M., Harper, J.L. and Townsend, C.R. (2006). Ecology: from individuals to ecosystems. Blackwell Publishing: Boston, MA.

Bell, S. (2012). Advice to the Minister for Sustainability, Environment, Water, Population and Communities from the Threatened Species Scientific Committee (the Committee) on an Amendment to the List of Threatened Ecological Communities under the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act). Weeping Myall – Coobah - Scrub Wilga Woodland/Low Forest of the Hunter Valley.

Bell, S. and Driscoll, C. (2014). *Acacia pendula* (Weeping Myall) in the Hunter Valley of New South Wales: early explorers' journals, database records and habitat assessments raise doubts over naturally occurring populations. *Cunninghamia* 14, 179–200.

Bell, S. and Driscoll, C. (2016). Hunter Valley Weeping Myall Woodland – is it really definable and defendable with and without Weeping Myall (*Acacia pendula*)? *Cunninghamia* 16, 15-30.

Dyer J. M. (2009). Assessing topographic patterns in moisture use and stress using a water balance approach. *Landscape Ecology* 24, 391-403.

Sivertsen, D., Roff, A., Somerville, M., Thonell, J., and Denholm, B. (2011). Hunter Native Vegetation Mapping. Geodatabase Guide (Version 4.0), Internal Report for the Office of Environment and Heritage, Department of Premier and Cabinet, Sydney, Australia.

Stephenson N. L. (1990) Climatic control of vegetation distribution: the role of the water balance. *American Naturalist* 135, 649-670

Tozer, M. G., and A. Chalmers. 2015. Should Hunter Valley Weeping Myall Woodland in the Sydney Basin Bioregion be listed as a Threatened Ecological Community? *Cunninghamia* 15:201-204.

Wiens, J.A., Stralberg, D., Jongsomjit, D., Howell, C.A. and Snyder, M.A. (2009). Niches, models, and climate change: assessing the assumptions and uncertainties. Proceedings of the National Academy of Sciences 106, 19729-19736.

Manuscript accepted 8 June 2016

Date of Publication:
July 2016

Cunninghamia
A journal of plant ecology for eastern Australia

The Royal
BOTANIC GARDEN
Sydney

ISSN 0727-9620 (print) • ISSN 2200-405X (Online)

The natural distribution and ecology of a Blue Mountains shrub, *Epacris browniae* (Ericaceae)

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***Abstract**:* The recently described shrub *Epacris browniae* (family Ericaceae) an endemic Blue Mountains species, occurs on treeless, dry, rocky, Sydney Montane Heath, on Narrabeen and Hawkesbury Sandstone in the upper Blue Mountains, 100 km west of Sydney, New South Wales, (c. 33° 40' S; 150° 22' E) at altitudes above 800 m, and within the 1300 mm Average Annual Rainfall isohyet. Based on our surveys in the Blue Mountains (incorporating 46 locations), the Area of Occurrence of the species is estimated at 525 square km, within which the Area of Occupation is 25 hectares. The northern limit is Mt Wilson, southern limit, Mt Solitary, western limit appears to lie between Clarence and Narrow Neck (Katoomba) and eastern limit is Lawson Ridge.

The species grows either on flat terrain or on gentle southern or western slopes, sometimes blending into escarpment complex, on soils of moderate acidity (pH 6.5–6.8) and good drainage, associated most commonly with *Banksia ericifolia* and, in descending order of abundance, with *Leptospermum trinervium*, *Allocasuarina distyla*, *Kunzea capitata*, *Allocasuarina nana* and *Hakea dactyloides*.

Epacris browniae flowers in November and seeds ripen in March. Seeds are shiny, brown, minutely warty, about 0.6 mm long, and weigh 0.038 mg.

Epacris browniae does not resprout after fire. Average stem diameters at three sites with known single fire histories correlate strongly with likely maximum age and confirm that the species is a facultative reseeder with a potential lifespan of up to 50 years.

Despite its relatively narrow habitat and area of occupancy *Epacris browniae* is well conserved within National Parks in the Blue Mountains but its susceptibility to *Phytophthora*, an exotic pathogen in the Blue Mountains is unknown.

***Cunninghamia* (2016) 16: 35-44**
doi 10.7751/cunninghamia.2016.16.005

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Introduction

The recently described species *Epacris browniae* (family Ericaceae), is an erect woody or stiffly robust shrub 0.5 to 2 m high (Coleby 2015). Major identifying characteristics are almost glabrous branchlets, leaves that are stiff, spreading and broadly trullate, with a blunt upturned apex and a concave lamina (Figure 1). Flower buds emerge singly from the leaf axils all down the stems of new growth: they flower basipetally, mainly in November (Figure 2).

The habitat for the species is treeless, dry, rocky, Sydney Montane Heath, scrub and escarpment complex (BMCC 2002), on either Narrabeen or Hawkesbury Sandstone in the upper Blue Mountains, 100 km west of Sydney, New South Wales. Limited data on the ecology were provided in Coleby (2015) and this paper enlarges on aspects of the habitat, range, rainfall and fire ecology of the species.

Methods

Sydney Montane Heath spans altitudes from 600 m to 1200 m, and has an open canopy of sclerophyll shrubs, 1–2 m tall, usually with emergent mallee eucalypts. There is often an open or patchy groundcover of sclerophyll sedges and herbs (Keith 2004). Using these habitat criteria, extensive searches for *Epacris browniae* populations were carried out in 2014 recording locations, map references, latitude/longitude, habits, habitats, plant associations and population abundance. Supplemented by data from 36 other sites discovered up to June 2015, the results were used to confirm the geographic range and distribution of the species, and associations with altitude, rainfall and geology.

The fire ecology of the species was given particular attention; it is a facultative reseeder, killed by fire and potentially vulnerable to frequent burning regimes. The root system of an old plant that died during the investigations showed no sign of a lignotuber (Figure 4). It was found in an area that had not been burnt since the 1957 Leura fires and, assuming that it was part of the early post-fire recruitment, could have been up to 55 years old at the time of its death (in 2012). The diameter of the major woody stem was 30 mm. This fact suggested that if stem diameters at a site could be correlated with time since the last fire, a picture of the population dynamics of the species over periods of up to 50 years could be established.

Fire records on the Geographic Information System (GIS) of the NSW National Parks and Wildlife Service (NPWS) were examined. Older wildfire histories (before about 1960) are not necessarily accurate in terms of either spatial range or intensity, but wildfire histories in more recent decades are more reliable in terms of range. No indication of the intensity of wildfires is available.

A source of error in assessment of wildfire impact is the often patchy nature of a burn (Figure 3); some areas within the fire zone may be obliterated while, metres away, the adjoining terrain can be largely untouched. This feature can have a significant effect on the distribution of native plants. It may be that the chance survival of some species in this situation allows both reseeders and resprouters to recolonise their terrain. In a few cases the GIS image for an area affected by wildfires of more than 2 per decade shows patchy later burns. Fire frequencies of more than 2 per decade may preclude adequate regrowth of either reseeders or resprouters.

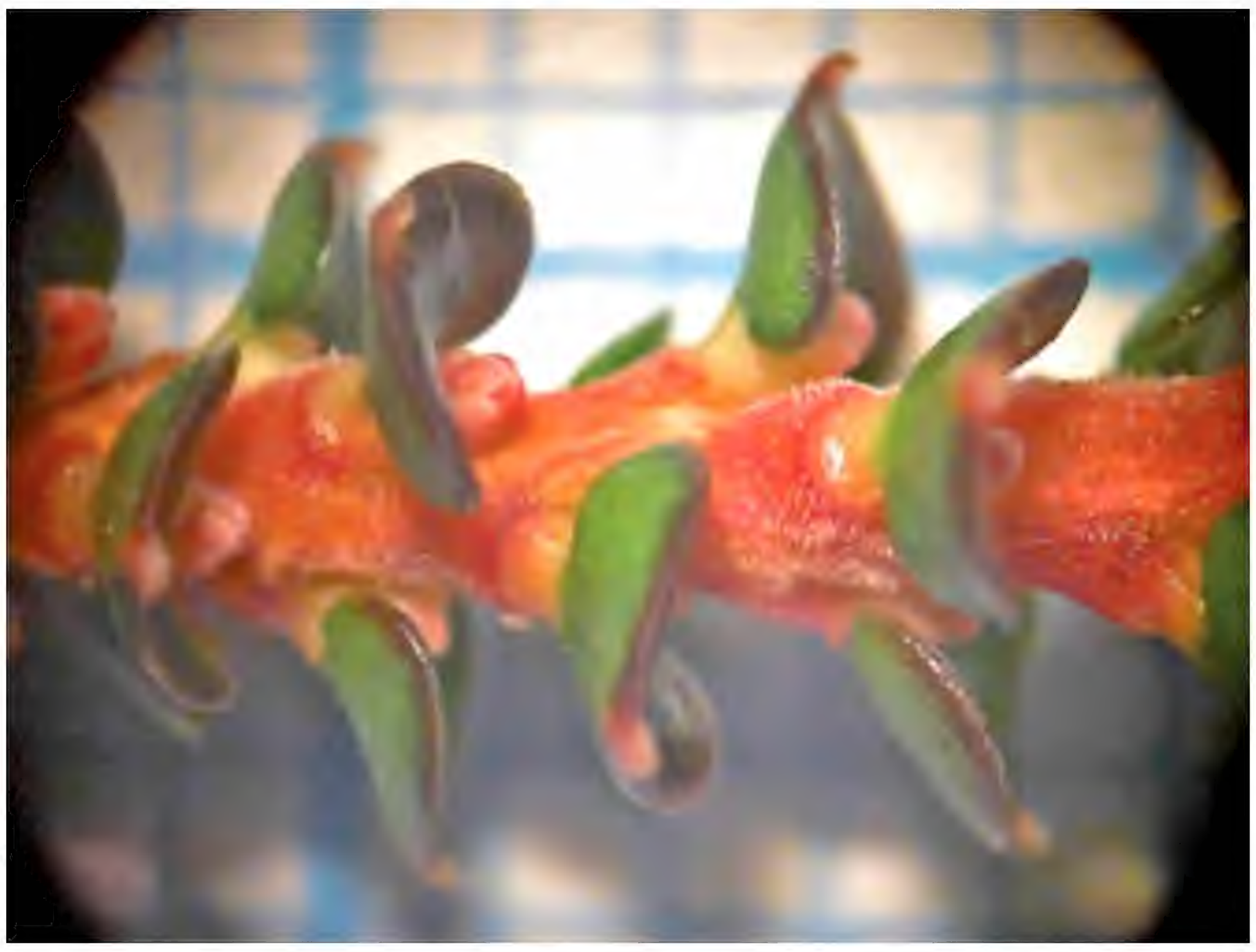

Figure 1: *Epacris browniae*: almost glabrous branchlet, broad trullate spreading leaves with a blunt apex, robust petioles and axillary flower buds (Background scale is 1 mm).

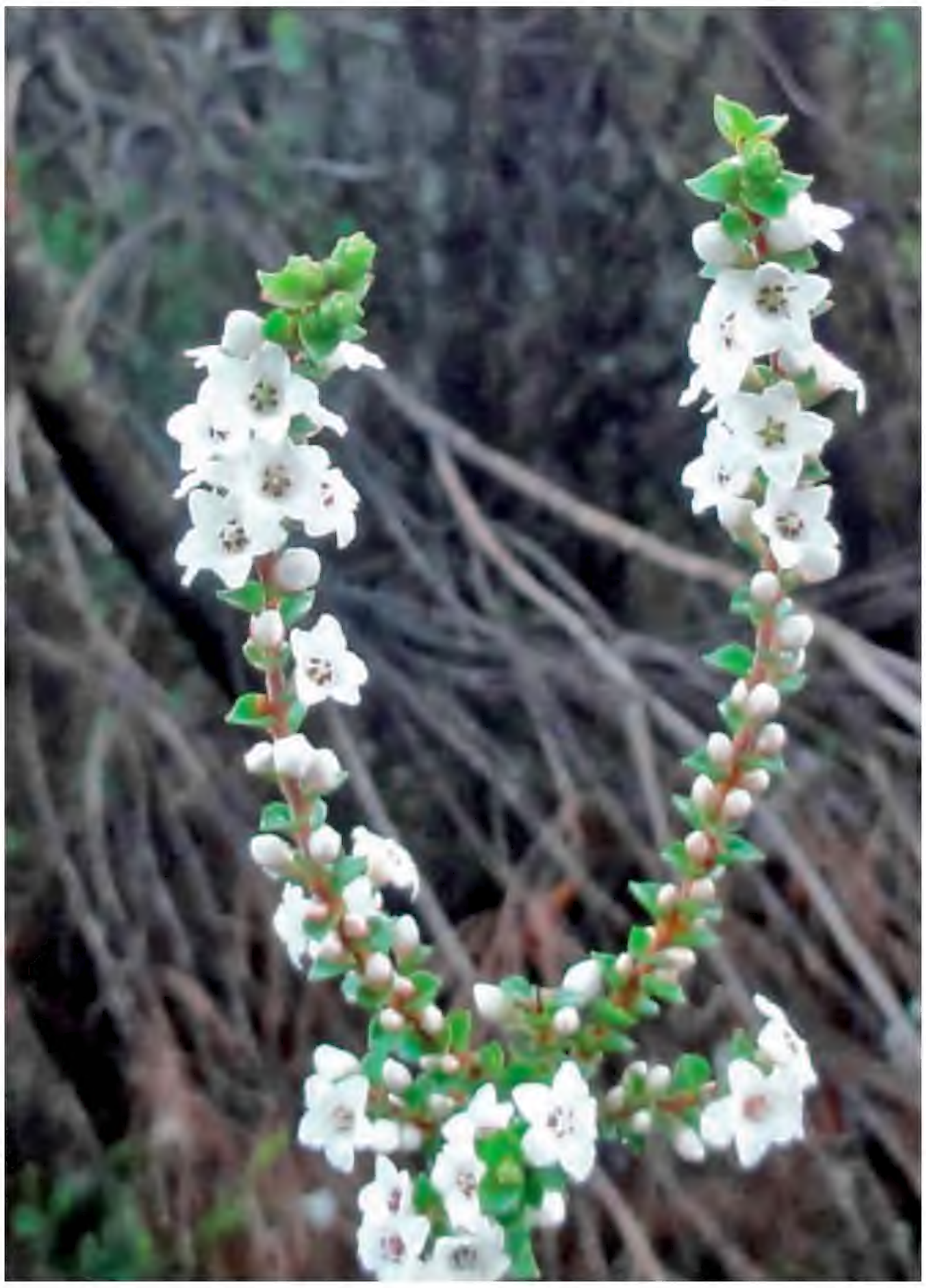

Figure 2: Epacris browniae, basipetal inflorescence, November 2015.

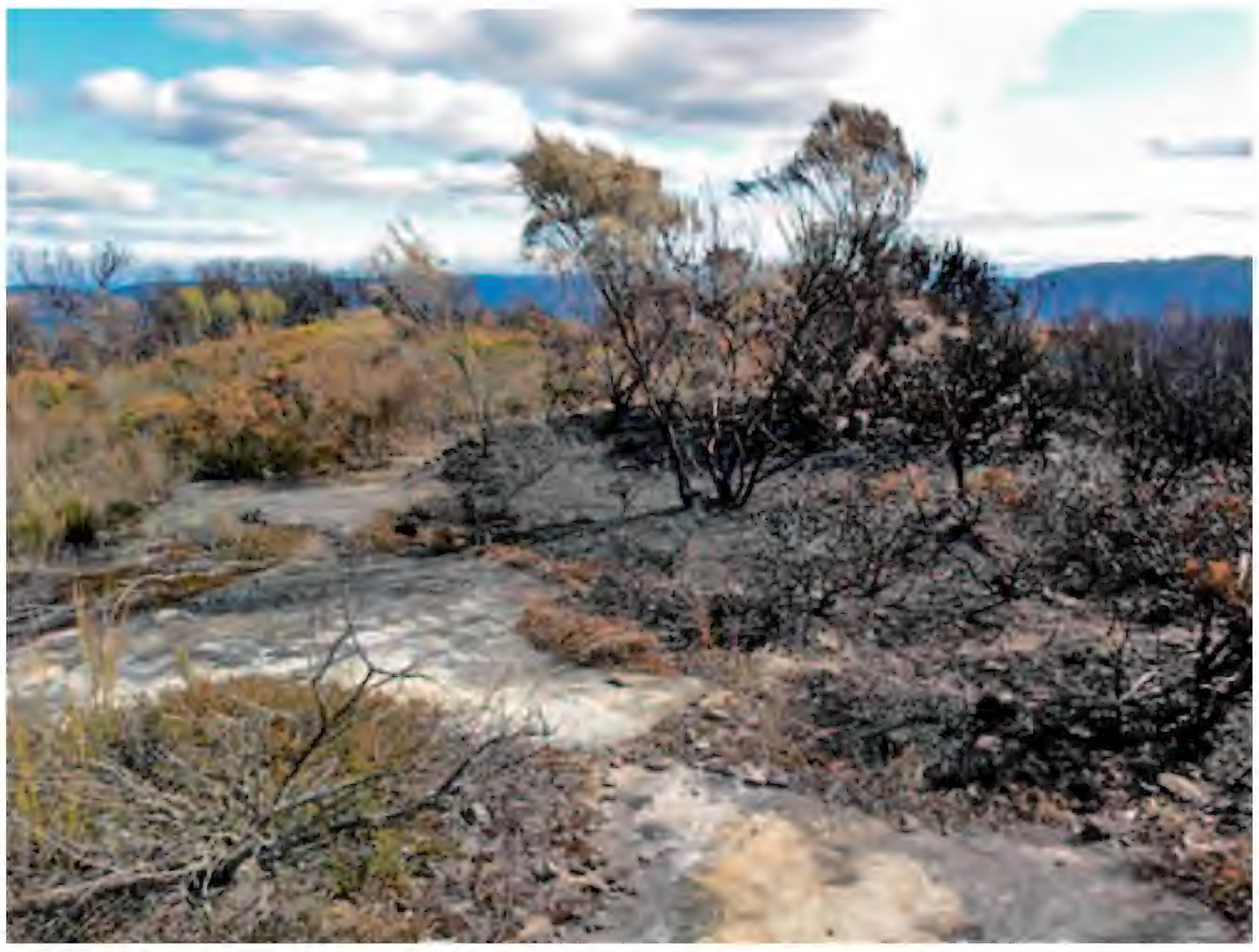

Figure 3: Wildfire burn at Lincoln's Rock, Kings Tableland, Wentworth Falls, August 2015.

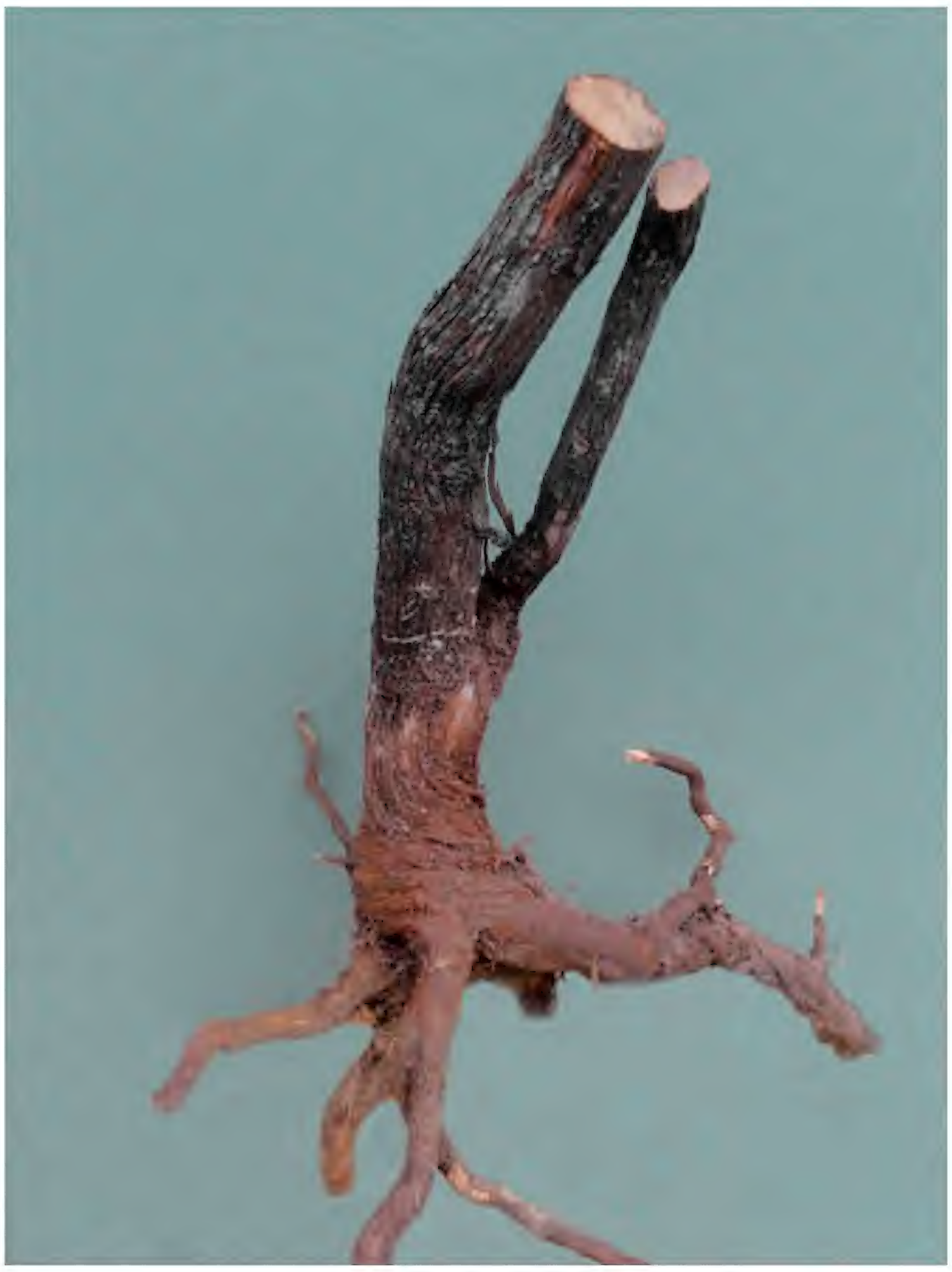

Figure 4: No sign of a lignotuber on old mature *Epacris browniae* plant.

Some 20 *Epacris browniae* sites were assessed for further study but most populations have experienced such complicated fire histories that assessments of age distributions could not be made. However, there were three sites where recent fire histories were straightforward (a fourth, Kings Table, was considered but rejected because of recent changes in human usage and management practices).

The three sites chosen for study were:

- **Flat Top summit, Mt Hay Road north of Leura** (33° 39' 21" S; 150° 22' 11.3" E), an area of several hectares of remnant Triassic Hawkesbury Sandstone last burnt in 2001-02. Some surrounding areas were burnt in 2002-03, but did not affect the summit. The age distribution of *Epacris browniae* on the summit of Flat Top could be up to 14 years.
- **Rocky Knoll on Bells Line of Road, 300 m west of Mt Charles** (33 33' 14.5" S; 150 22' 26.4" E), another remnant of Hawkesbury Sandstone. Its principal characteristic is its hardness. The western slope of the hard, smooth sandstone retains little or no soil, and the surface has been polished by wind and weather. This area was last burnt in 1993-94, and had not been previously burnt since 1979-80. Surroundings areas (such as Mt Charles itself) have been burnt at least once since 2000. The age distribution of *Epacris browniae* at Rocky Knoll could therefore span at least 20 years from 1994.
- **Sunset Rock on Kings Tableland (off Kedumba Road),** (33° 45' 47.4" S; 150° 22' 19" E), a clifftop site of Banks Wall Sandstone that experiences high orographic rainfall and has not been burnt for more than 50 years. It escaped burns in surrounding areas in 1964-65, 1977-78, 1988-89, 1999-2000, 2002-03, 2006-07 and 2015. The age distribution at this site could well be up to 50 years. There may be older survivors amongst the re-emergent population.

At least 48 plants in each population were sampled, but the nature of some habitats prevented a true random sampling. Instead an attempt was made to represent the size/age distribution of each population as accurately as possible. Each sample plant was measured for (a) height and (b) stem diameter 100 mm above ground level. Where multiple stems were present the sum of their diameters was recorded. For each location the average stem diameter (with standard deviation and standard error of the mean) was calculated.

Results

Geographic Range

Using the habitat criteria for targeted searches, populations of *Epacris browniae* were recorded at 46 locations in the upper Blue Mountains 100 km west of Sydney. The northern limit is Mt Wilson, and the southern limit is Mt Solitary. The western limit appears to lie between Clarence and Narrow Neck (Katoomba). The eastern limit appears to be Lawson Ridge. The Area of Occurrence was estimated at 525 square km (Figure 5) within which the Area of Occupation was 25 hectares.

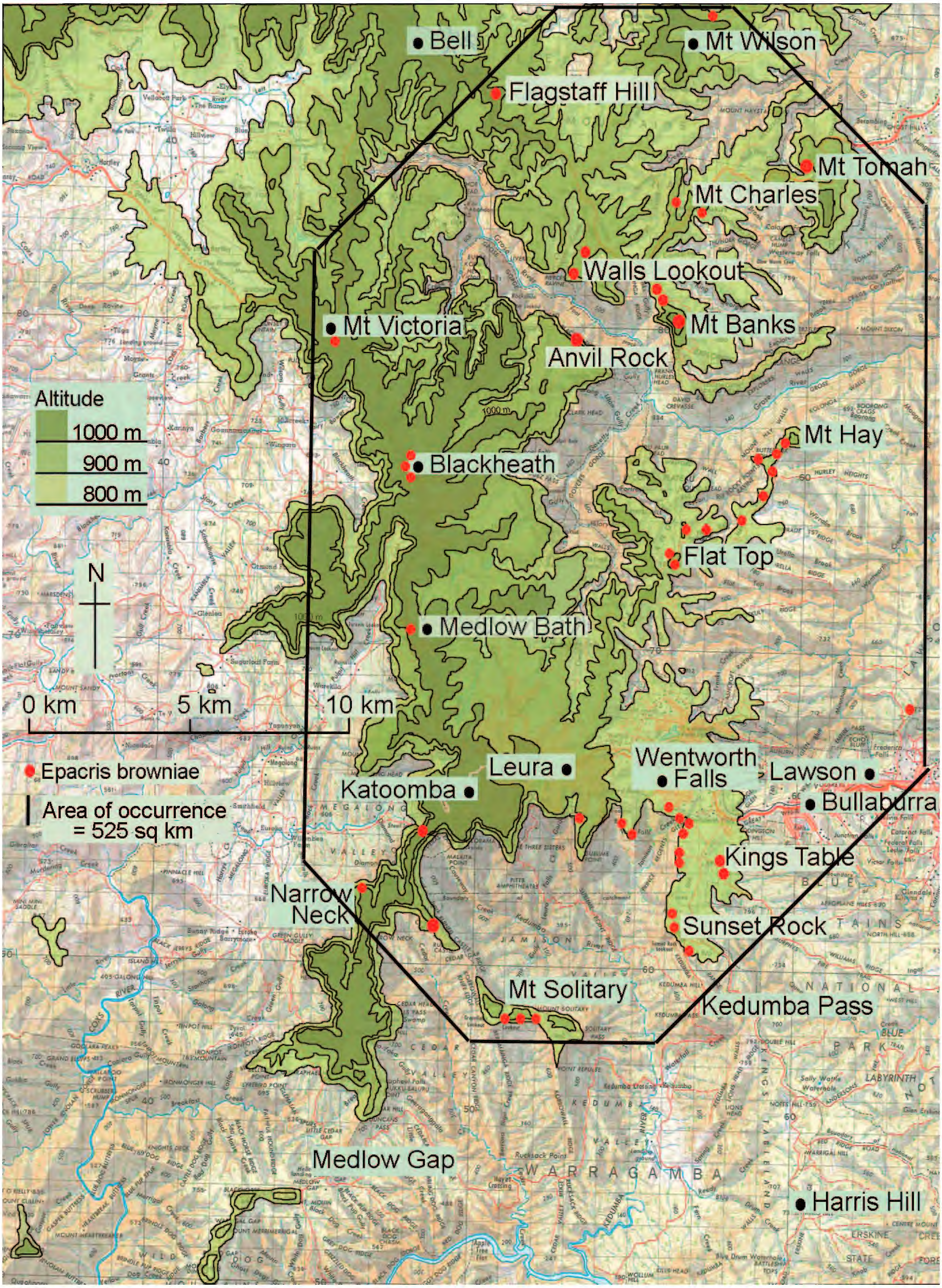

Figure 5: Occurrences (red dots ●) of *Epacris browniae* in the upper Blue Mountains, showing geographic correlation with altitude, and Area of Occurrence.

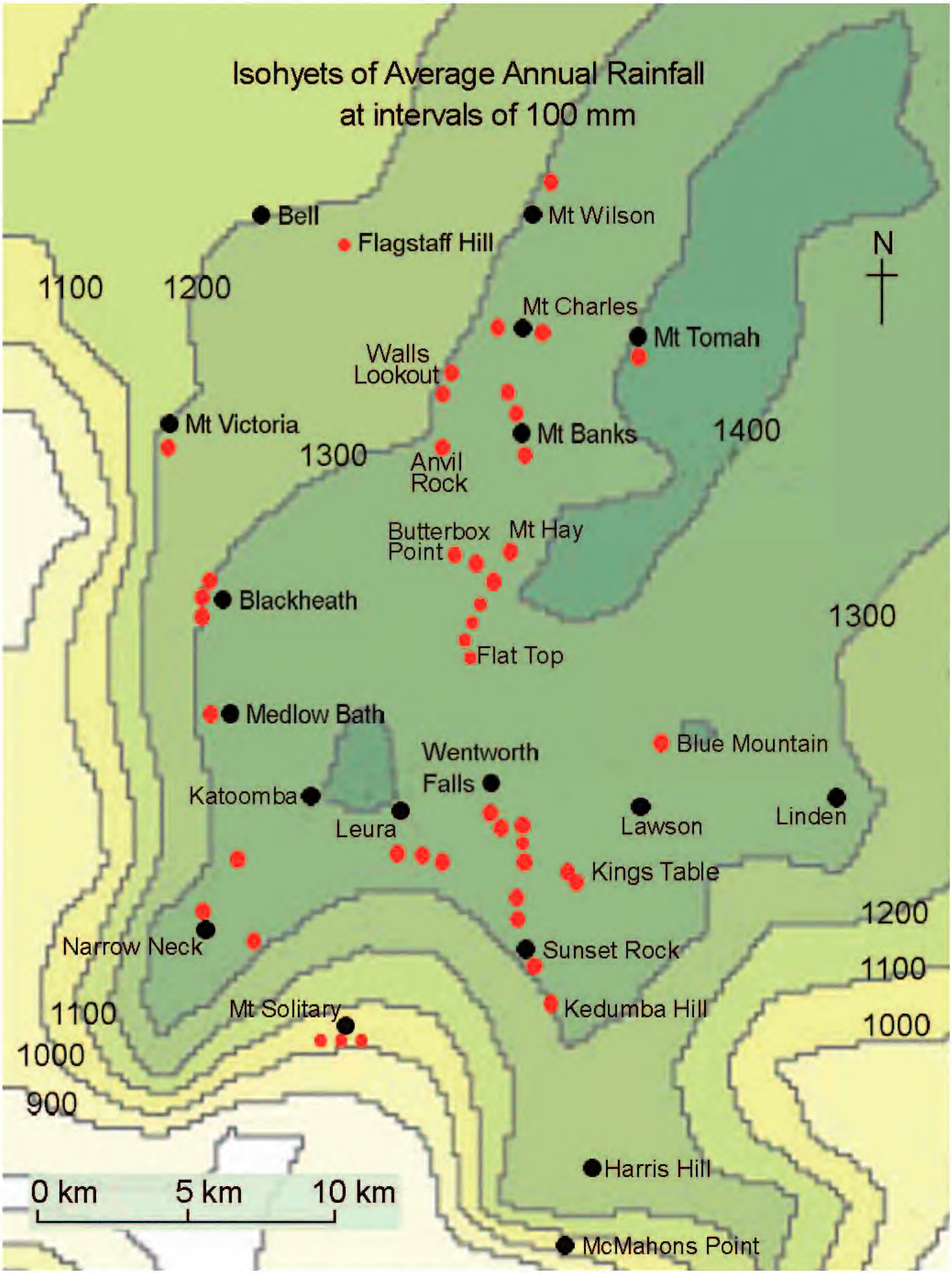

Figure 6: Occurrences (red dots ●) of *Epacris browniae* in the upper Blue Mountains, showing geographic correlation with average annual rainfall.

Altitude

Occurrences of *Epacris browniae* correlate strongly with altitudes over 800 m (Figure 5) with populations recorded between elevations of 800 m and 1100 m. (A few small map areas northwest of Bell exceed 1100 m: they are not shown in Figure 5.) Further searches of suitable habitat may extend this geographic range, but the evidence indicates that the species is endemic to the upper Blue Mountains. North and east of Mt Wilson and Mt Tomah, in the Wollemi National Park, might also be suitable habitat. However, this remains unresolved because of rugged terrain and lack of access.

Rainfall

Populations of *Epacris browniae* occupy habitat that receives relatively high rainfall and are almost wholly within the 1300 mm isohyet of average annual rainfall (Figure 6) derived from a larger sketch map (BoM 2015) based on Standard 30-year Climatology 1961–1990.

The inference that might be drawn from Figure 5 is that more *Epacris browniae* might be found in Blue Mountains National Park north and east of Lawson, where the average annual rainfall is still over 1300 mm. However, except for one outlying occurrence near the summit of Blue Mountain (725 m), none was found at these lower altitudes (approximately 600–700 m) during a search of Sydney Montane Heath along Queens Road, Binnowie Drive, and out to the lookout overlooking the junction of Mt Hay Creek and Wentworth Creek adjoining the Kolonga Labyrinth. This suggests that both altitude and high rainfall contribute to suitable habitat.

Geology

The Blue Mountains is an uplifted, tilted and dissected peneplain stretching from low (150 m) elevation in the east near Penrith, to high (1100 m) in the west near Lithgow. The relatively soft Wianamatta Shales have all been eroded from the upper Blue Mountains, and the underlying Hawkesbury Sandstone survives in only a few patches, (such as at Rocky Knoll and at Flat Top). Populations of *Epacris browniae* occur either on the upper members of the Narrabeen Group or on the Hawkesbury Sandstone. The distribution does not encompass the adjacent basalt caps, as these have sufficiently fertile soils to support Tall Forest, a habitat where *Epacris browniae* does not grow.

Epacris browniae grows in Sydney Montane Heath either on flat terrain or on gentle southern or western slopes, sometimes blending into Escarpment Complex; its preference is for dry rocky outcrops. It copes well with open sunny sites and dense montane scrub alike. It favours thin, rocky soils of moderate acidity (pH 6.5-6.8) and good drainage. Soil types are predominantly clayey sands, varying from buff to russet to grey in colour, deriving from Triassic Narrabeen or Hawkesbury Sandstone. These sandstones give rise to free-draining, sandy, depauperate siliceous soils of low phosphorus and clay content, typically yellow podsols and earths, lithosols and colluvial scree (BMCC 1997).

One of the more extreme habitats for *Epacris browniae* is on the south-western flank of Rocky Knoll, near Mt Charles (Figure 7). Sparse open vegetation of stunted shrubs survives in cracks and fissures but, surprisingly, the most abundant species is *Epacris browniae* which not only thrives in this habitat, but outcompetes other common species such as *Banksia ericifolia*, *Hakea dactyloides* and *Leptospermum trinervium*. *Epacris browniae* at this site appears to benefit from association with mosses and lichens.

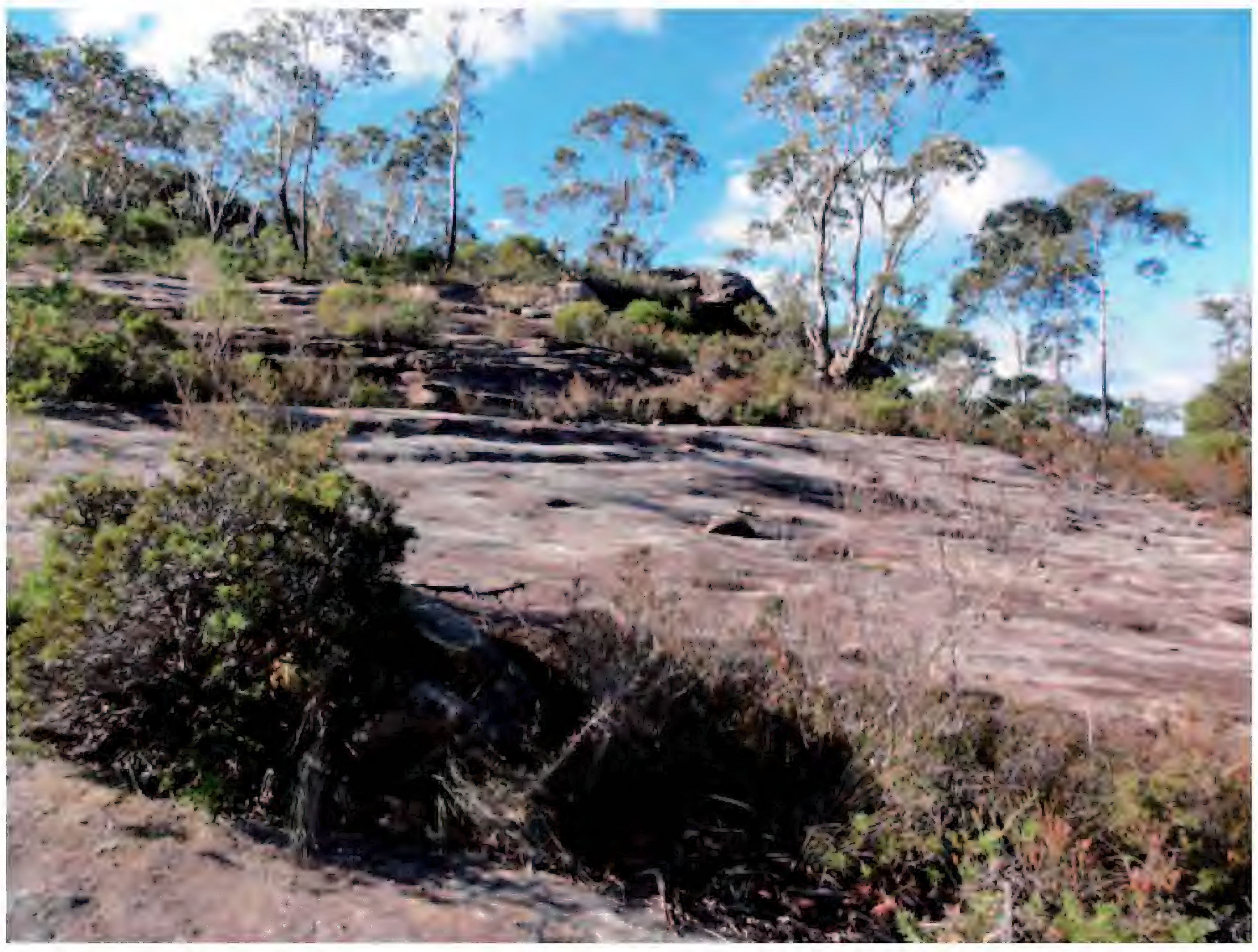

Figure 7: Rocky knoll site 300 m west of Mt Charles, last burnt about 20 years ago.

Population sizes

Large populations of *Epacris browniae* inhabit the northern end of Kings Tableland, southeast from Wentworth Falls (especially on Kings Table (about 1 ha) and along Kedumba Walls). Accessible sites include Lincolns Rock (1 ha), Podgers Hill and Sunset Rock (1 ha). One plant was found on the cliff line, southwest of Kedumba Hill, but none has been found further south.

Large populations were also found north of Leura on the summit and the surrounds of Flat Top (5 ha) and the whole of the high plateau (10 ha), from the end of the Mt Hay Road, north to Mt Hay and west to Butterbox Point. Other major sites are at Mt Banks (0.2 ha), Walls Lookout, Mt Wilson, Mt Tomah and Rocky Knoll (1 ha) near Mt Charles.

Along Narrow Neck Plateau, south of Katoomba there is a significant but scattered population (0.1 ha) on and around the approaches to Castle Head and Castle Cliff trig (986 m elevation). This location is about 8 km from Katoomba railway station, and is on the edge of the 1300 mm isohyet. *Epacris browniae* was not found further south along Narrow Neck. Large populations were found in southern escarpment complex on the summit of Mt Solitary.

Large populations (0.2 ha) were found in Sydney Montane Heath north and south of Fort Rock in Blackheath, and in areas of high tourist traffic along Sir H Burrell Drive, and the track down to and including Fletchers Lookout in Wentworth Falls.

Small populations (1–10 plants), were found on clifftops at Moya Point and on the Scout Trail north from Inspiration Point in south Leura, on a small rocky outcrop at the end of Delmonte Avenue west of Medlow Bath, and on the summit of Flagstaff Hill near Bell. A single plant was found on the west of Sublime Point in south Leura.

Associated species

Epacris browniae is associated most commonly with shrubs: *Banksia ericifolia* (95%) and, in descending order of importance, with *Leptospermum trinervium*, *Allocasuarina distyla*, *Kunzea capitata*, *Allocasuarina nana* and *Hakea dactyloides* (40%). Other associated shrub species include *Boronia floribunda*, *Epacris rigida*, *Conospermum taxifolium*, *Mirbelia rubioides* and *Dillwynia retorta*.

Reproduction

Epacris browniae flowers principally through November with seeds ripening in March. Like many other *Epacris* species, it has small brown seeds in papery capsules of relatively short persistence on the plant. Seeds are about 0.6 mm long, elliptical, hard, brown, shiny and minutely warty, and shaped like a miniature, half-inflated rugby football (Figure 8). Mean seed weight is 0.038 mg (pers. comm. Richard Johnstone, Seed Bank Officer, Australian Botanic Garden, Mt Annan). Howell (PlantNET) reports that seeds of a similar species, *Epacris microphylla,* weigh 0.03 mg.

Nothing is known about seed dispersal vectors for *Epacris browniae*, but local dispersal by gravity, wind and water are probably significant, possibly aided by small insects. Nothing is known about seed longevity, dormancy, germination requirements, time to first flowering and time to first fruiting, although some of these features may be resolved by observations on Kings Tableland, Wentworth Falls following the August 2015 fire (which burnt some 500 ha of bush, including populations at Lincolns Rock (Little Switzerland Road) and Podgers Hill (ANF)).

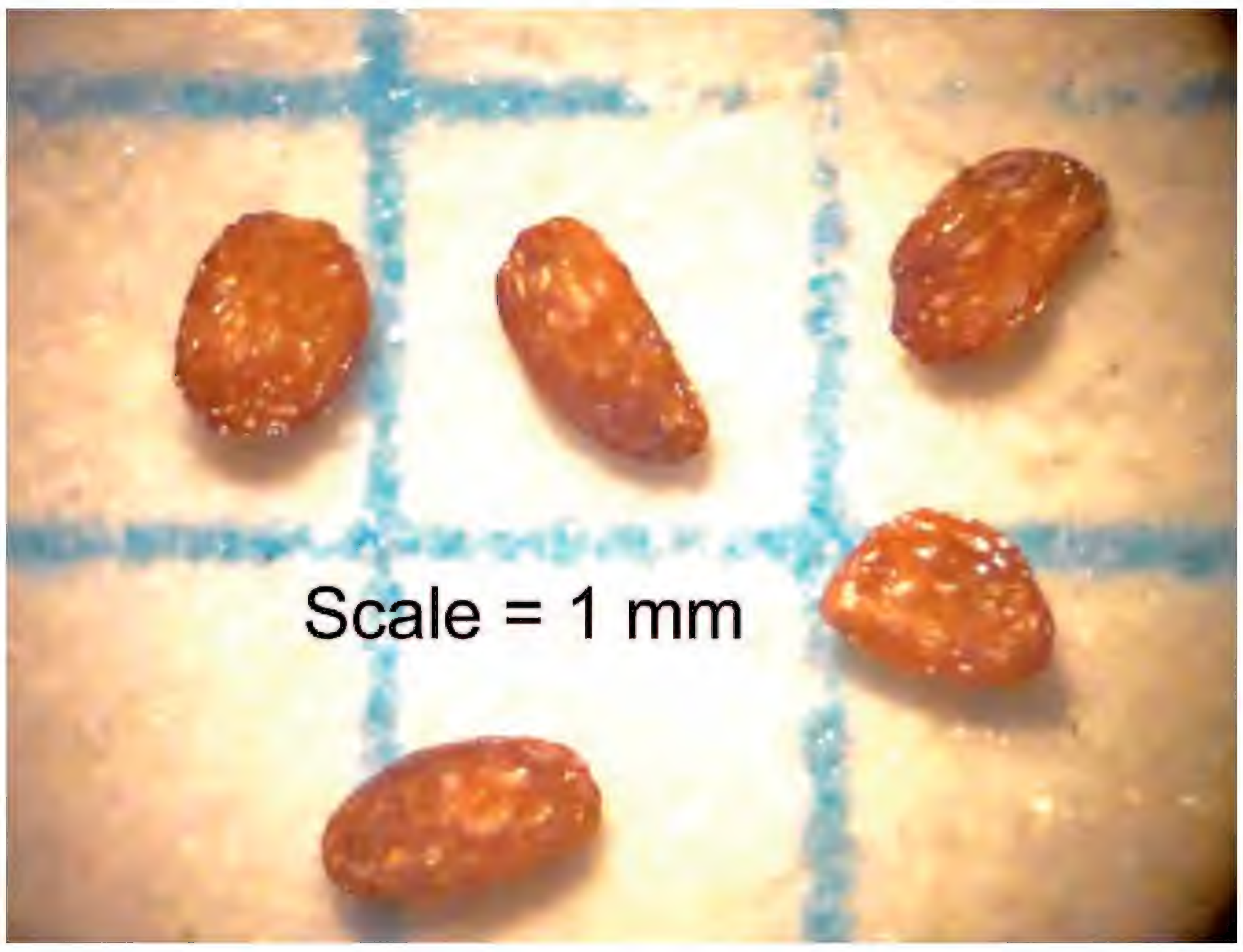

Figure 8: Seeds of *Epacris browniae;* mean seed weight is 0.038 mg.

Fire response

Epacris browniae does not spread vegetatively and since there is no lignotuber in young or mature plants it is unlikely to resprout after fire. For example there have not been any resprouting *Epacris browniae* plants at Podgers Hill: Figure 9a shows *Epacris browniae* before the fire of 1 August 2015, and Figure 9b shows the same site in December 2015, four months after the fire. The obvious regrowth is that of *Eucalyptus stricta*, and monocots. It is therefore considered a facultative seeder that relies on a long-term soil seedbank that survives fire.

Some reseeder species may include a small percentage of plants that survive fire and resprout, especially where the rootstock is buried sufficiently deeply to avoid being burnt, or where the fire has been either low intensity or patchy (Burrows 1995, Auld 1996). A population of plants may exhibit some very old plants from before the last fire but there is no way of identifying this feature unless some burnt remains persist; none was found on any plants we measured.

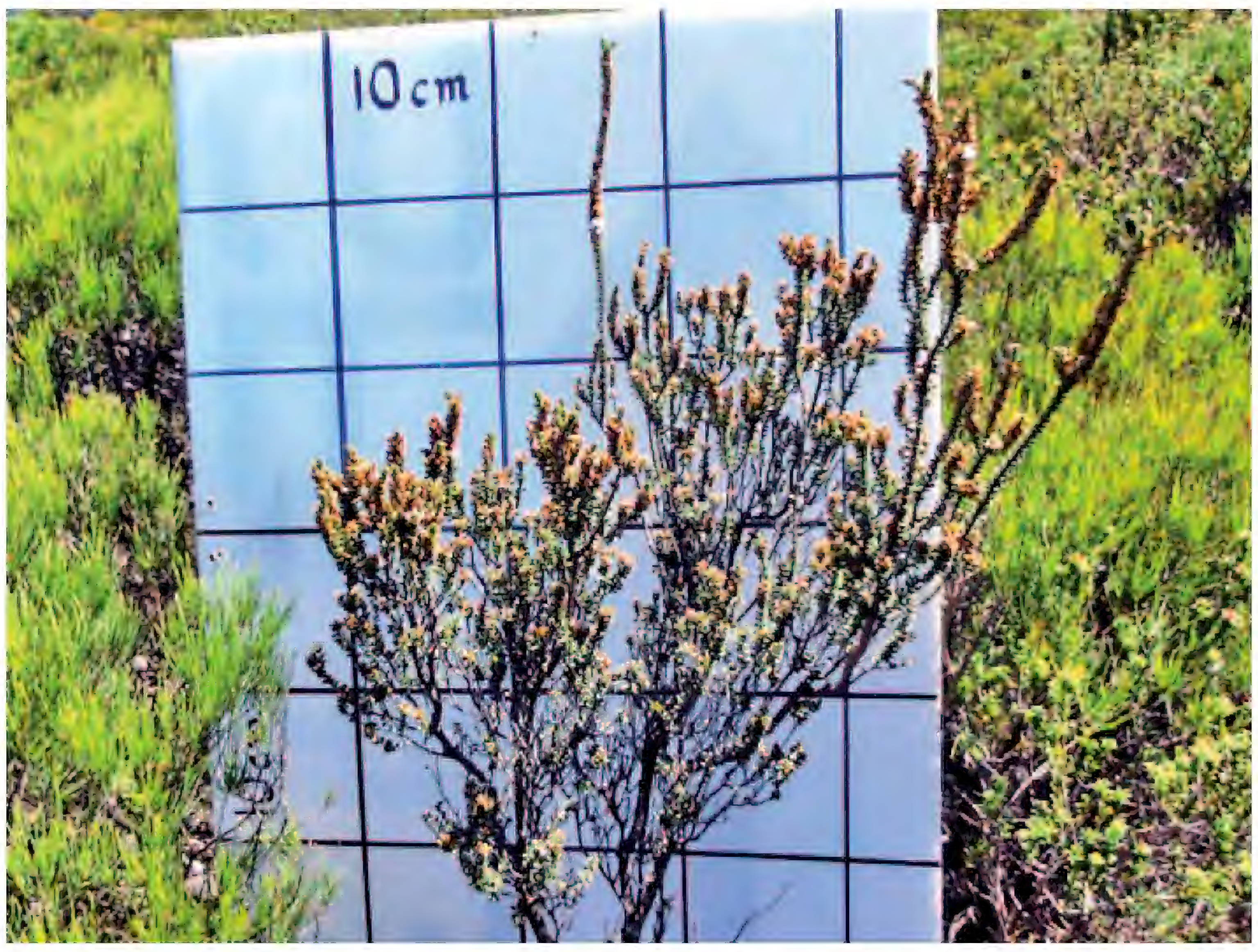

Figure 9a: *Epacris browniae* at Podgers Hill, December 2013.

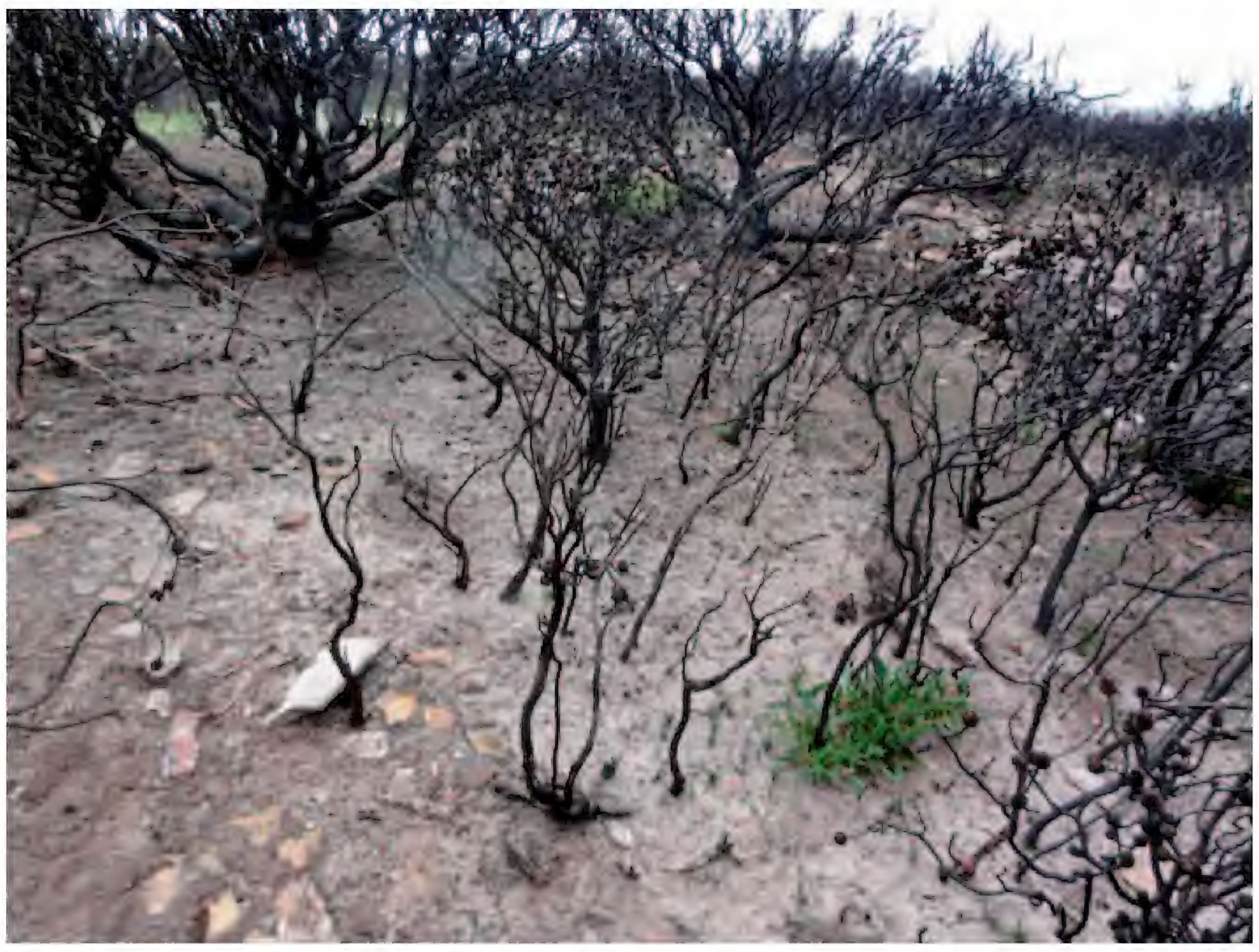

Figure 9b: The same view as Figure 13a at Podgers Hill, December 2015.

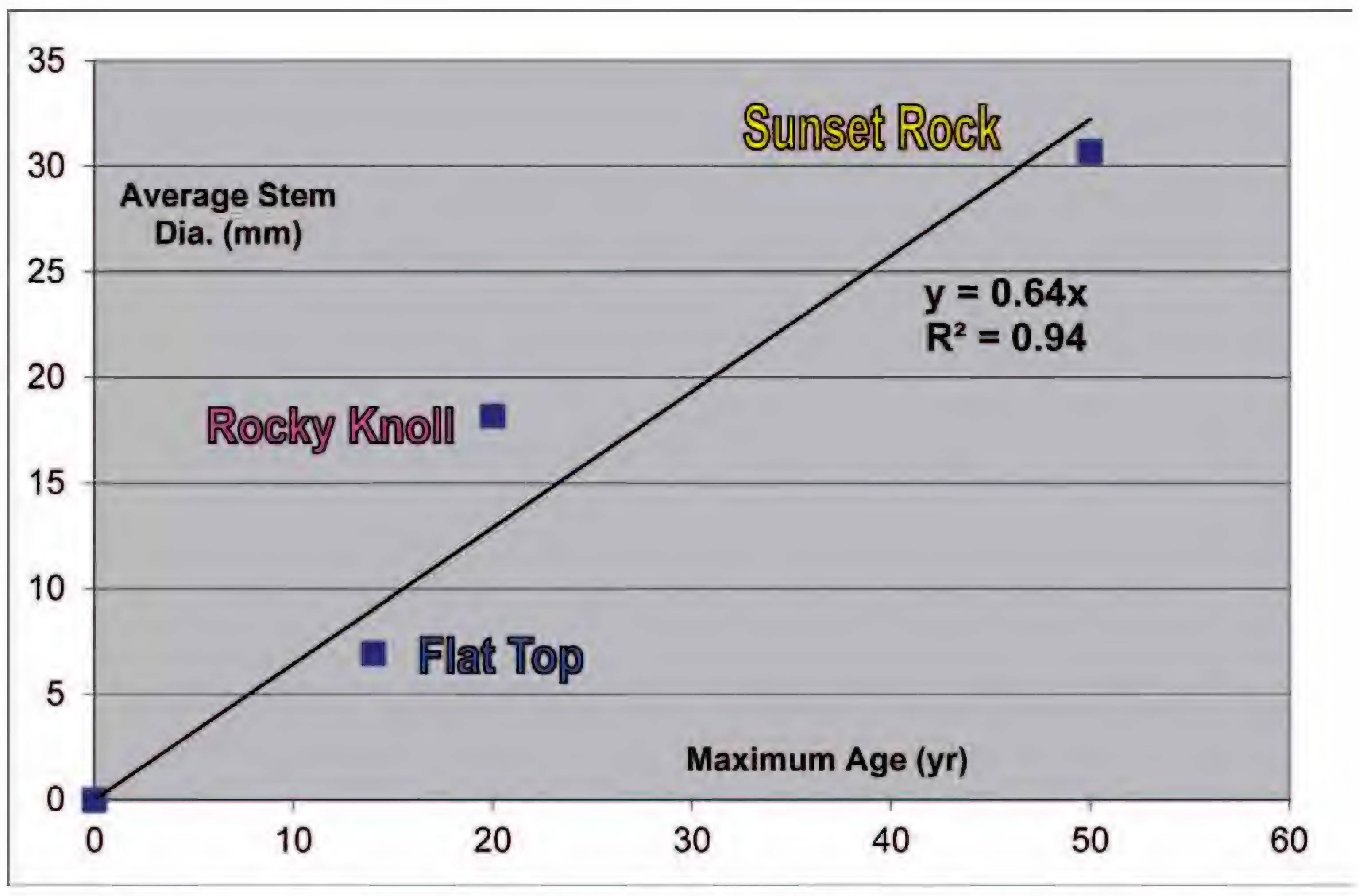

Figure 10: Average Stem Diameter vs. Maximum Age.

Assuming it is a facultative reseeder, the size distributions of stem diameters in three populations of *Epacris browniae* (Figure 10) indicate a correlation of average stem diameters with population age with a reasonable degree of confidence. Thus, one could measure the average stem diameter in a population of *Epacris browniae* and then deduce its likely maximum age. Our results indicate that plants can live to over 50 years. This approach might also be applicable to other perennial species.

Longevity

For each of the three sites with known single fire history, the numbers of plants were plotted against stem diameters measurements. In each case the average number in a given stem diameter category was calculated along with the standard deviation and the standard error of the mean (Table 1). No significant relationships were found for plant height, which can vary according to individual position and exposure. The stem diameter measurements are a more realistic guide to plant age and correlations with likely age are shown for Flat Top (Figure 11), Rocky Knoll (Figure 10) and Sunset Rock (Figure 13). Figure 12 shows the average stem diameter for each of the three populations against their likely maximum age. The slope of the plot is 0.64, and $R^2 = 0.94$.

Table 1: Statistical data for *Epacris browniae* from three sites; average stem diameter, standard deviation, standard error of mean, range of stem diameter, number of plants in each sample, and known maximum age based on last fire event.

	Av Stem Diameter (mm)	Standard Deviation of Average	Standard error of mean	Range of Stem Diameters	Number of Plants (n) in sample	Known Maximum age (yr)
	0	0	0	0	0	0
Flat Top	6.94	3.4	0.5	2–15	48	14
Rocky Knoll	18.2	14.8	2.1	2–72	48	20
Sunset Rock	30.7	38.7	4.7	1.5–239	72	50

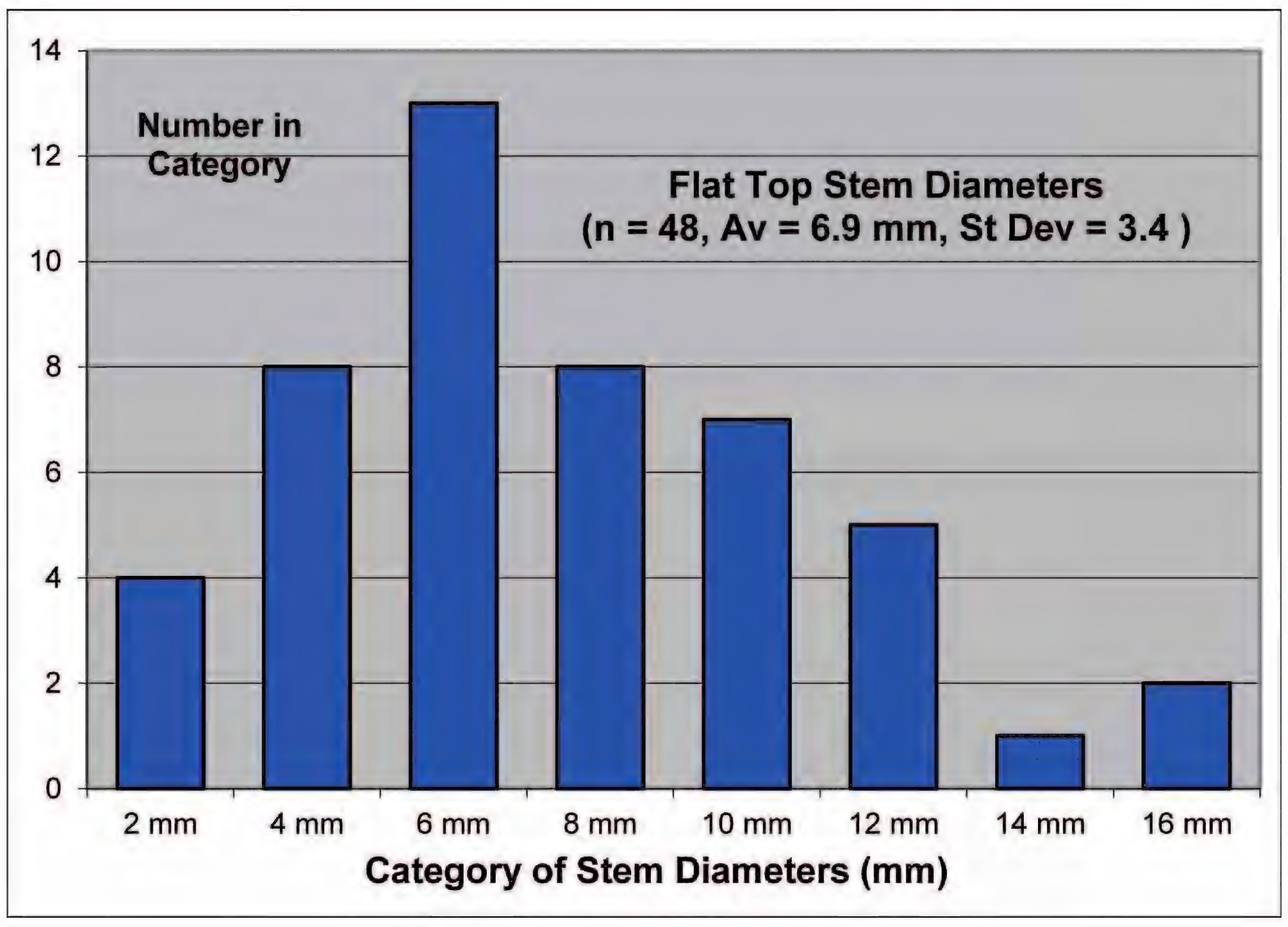

Figure 11: Histogram of Flat Top Stem Diameters.

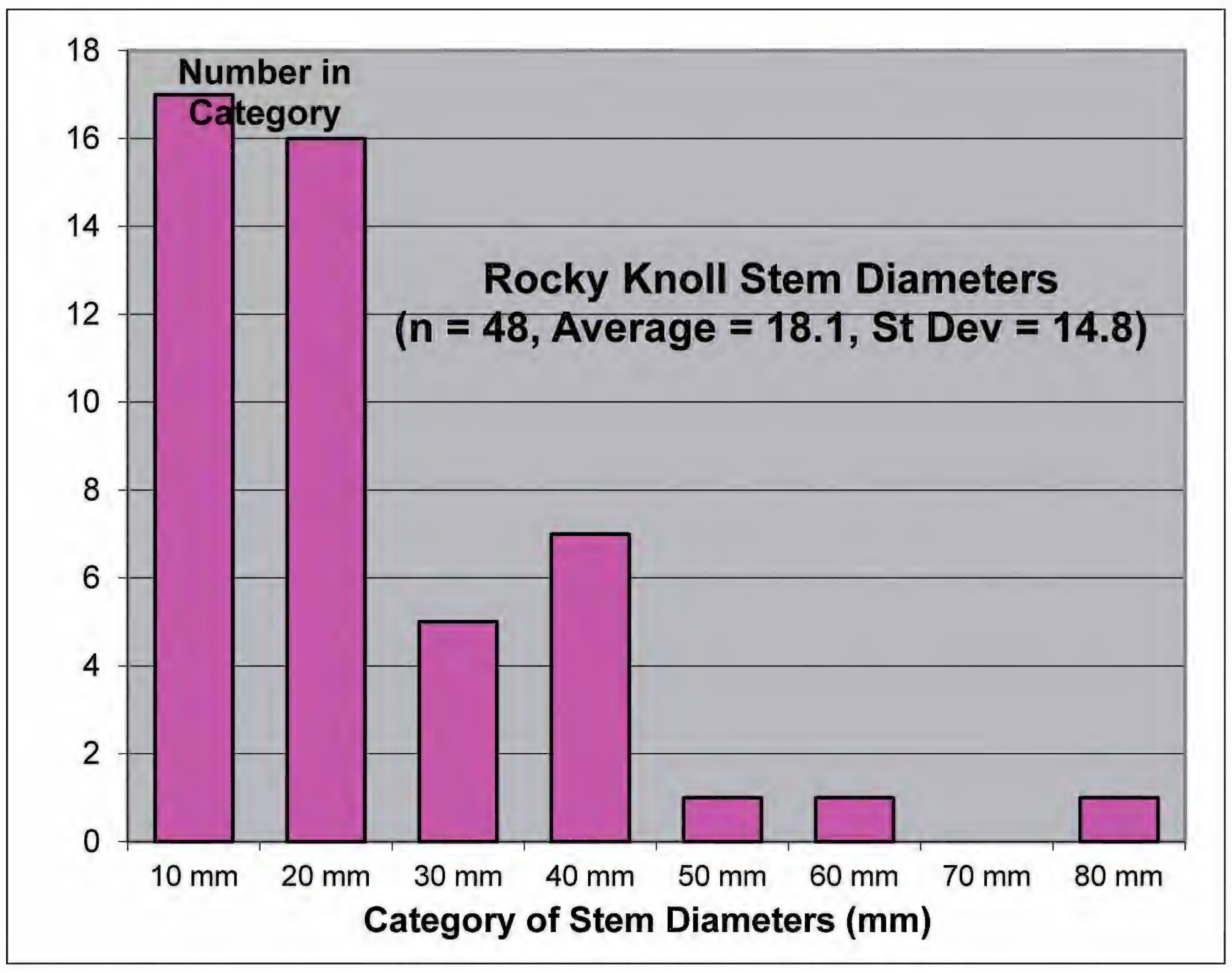

Figure 12: Histogram of Rocky Knoll Stem Diameters.

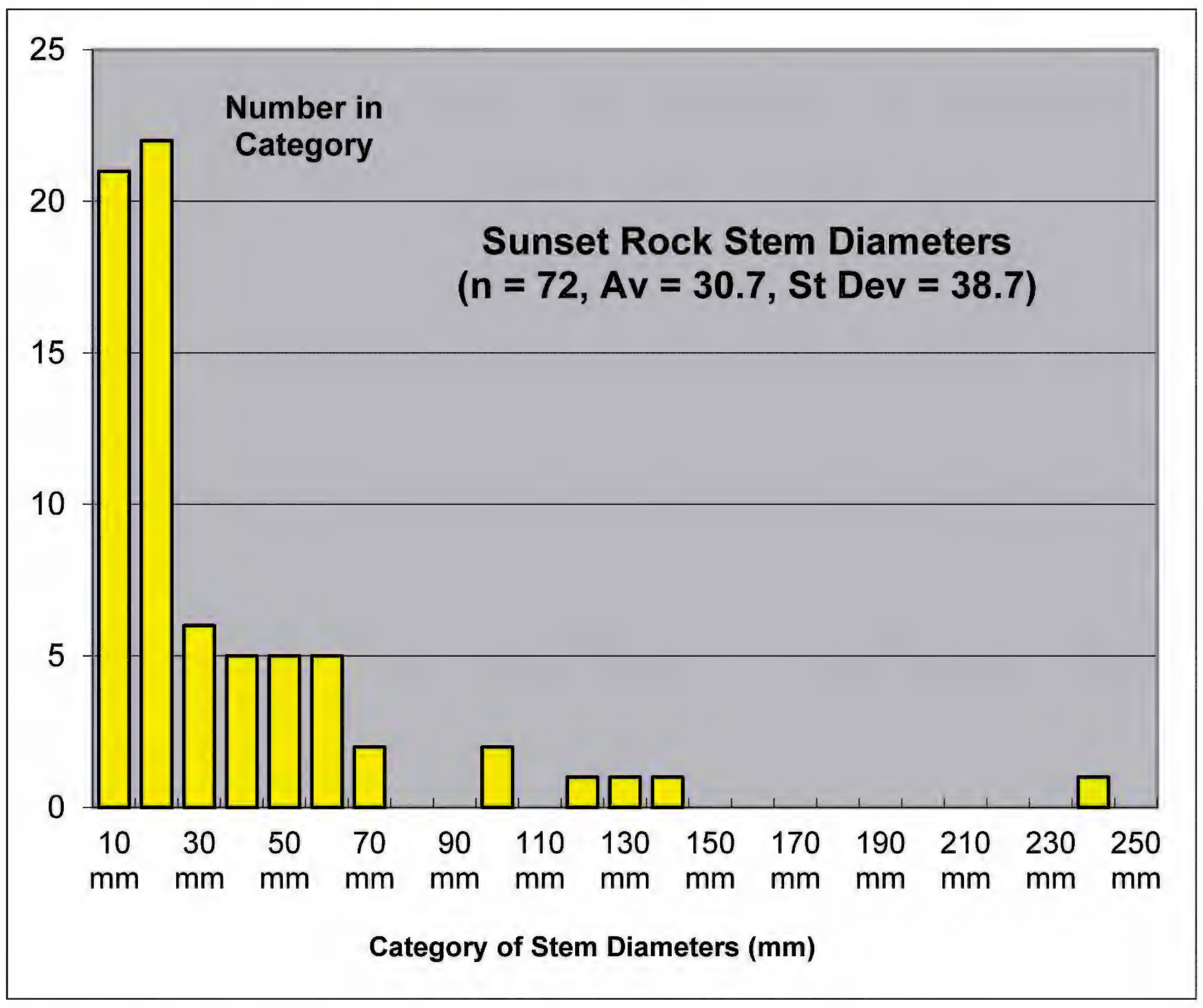

Figure 13: Histogram of Sunset Rock Stem Diameters.

Discussion

Habitat comparison with Epacris obtusifolia

Epacris browniae does not grow in association with trees, nor in swamps, soaks, bogs, fens or any other wet places. In contrast *Epacris obtusifolia* grows over a far greater range of altitude and rainfall but predominantly in soils that remain wet for long periods. Such conditions occur in the upper Blue Mountains where there are high clay content soils within the 1300 mm isohyet of average annual rainfall. A localised example of the comparable habitat requirements of the two species is evident on the summit of Flat Top (929 m elevation) on the Mt Hay Road. Over several more or less flat treeless hectares, *Epacris browniae* and *Epacris obtusifolia* lie side by side in patches (metres in diameter), the former occupying slightly higher ground with better drainage, the latter preferring slight depressions with poorer drainage. Both species may also be found on the steep slopes of Flat Top, *Epacris browniae* where it does not get waterlogged, *Epacris obtusifolia* where it does. The two species flower together in early November, although at that time *Epacris obtusifolia* is coming to the end of its flowering period (normally September through October in the upper Blue Mountains).

Association with Epacris microphylla

Along Little Switzerland Road (Wentworth Falls) *Epacris browniae* grows in tall Sydney Montane Heath alongside *Epacris microphylla* var *microphylla,* which occupies short Sydney Montane Heath. *Epacris microphylla* flowers mainly in September (although some nearby populations begin to flower in June). *Epacris browniae* flowers in November.

Association with Epacris rigida

The closely-related *Epacris rigida* has a lignotuber and may be less dependent on seed for post-fire recruitment as *Epacris browniae*. Both species are found together at Sunset Rock (Kings Tableland) and on the approaches to Mt Hay. *Epacris rigida* occurs alone on the steep smooth sandstone outcrop of Notts Hill (730 m) on Kings Tableland.

Comparison of geographic ranges of other Epacris species

The natural geographic distribution of *Epacris browniae* is much smaller than that of *Epacris microphylla* var *microphylla*, a species within which it was formerly included. Whereas *Epacris browniae* is restricted to the upper Blue Mountains at altitudes above 800 m, *Epacris microphylla* var *microphylla* is widespread from coast to mountains, all along the eastern seaboard of NSW, and from Rockhampton in Queensland to the Victorian Alps and throughout Tasmania (PlantNET 2015, Australia's Virtual Herbarium 2015). *Epacris microphylla* var *microphylla* occupies swampy heath and drier coastal heath, two habitats that are inimical to *Epacris browniae*.

The geographic range of *Epacris browniae* is also much smaller than that of *Epacris brevifolia*, *Epacris gunnii, Epacris obtusifolia* and *Epacris pulchella*, all of which are found in the Blue Mountains, but extend to Queensland and (with the exception of *Epacris pulchella)*, also extend to Victoria (AVH). Several other species of *Epacris* are commonly encountered in the Blue Mountains, of which *Epacris coriacea, Epacris rigida* and *Epacris purpurascens* var *onosmiflora* each have a distribution centred on Sydney and the Central Tablelands. Species such *Epacris muelleri* and *Epacris rhombifolia*, are much less common, though more widespread. *Epacris celata* is principally a species of the Victorian Alps and Kosciusko. All these species of *Epacris* (except for *Epacris obtusifolia* and *Epacris pulchella*) have flowers where the corolla tube is shorter than the sepals, and the lobes are as long as, or longer than the tube.

Conservation and management implications for Epacris browniae

Despite its relatively narrow habitat and restricted area of occupancy *Epacris browniae* is well conserved within National Parks in the Blue Mountains; indeed because of the ruggedness of its habitat it is likely that most of its original presettlement (i.e. pre 1788) extent still remains. A general consideration however is that of possible change in both temperature and rainfall. As the rainfall isohyets of Figure 6 are relevant only for 1961-1990, subsequent changes (such as climate change) may invalidate conclusions concerning future rainfall patterns and effects upon the distribution of *Epacris browniae*.

Therefore although *Epacris browniae* is well conserved, the impact of frequent fire needs to be considered for some local populations. The other potential threat, particularly in the context of increasing temperatures and rainfall, is the spread of exotic pathogens such as *Phytophthora*; see for example Green (2016) for impacts on the shrub *Nematolepis ovatifolia* in Kosciuszko National Park. The susceptibility of *Epacris browniae* is unknown.

Conclusion

Epacris browniae is an upland species with habitat over 800 m elevation, average annual rainfall of over 1300 mm, good drainage, gentle southern or western slopes which may blend into Escarpment Complex. It inhabits the upper range of treeless Sydney Montane Heath. Soils are rocky, thin clayey sands derived from either Narrabeen or Hawkesbury Sandstones with pH 6.5–6.8. In these respects its habitat and range are more restrictive than those of its close relatives, *Epacris microphylla* var *microphylla* and *Epacris rigida,* and of its more distant relative *Epacris obtusifolia*.

Plants are robust, erect, woody or stiffly wiry, can tolerate exposure to wind and sun and are commonly 0.5 to 1.5 m high; in sheltered places (as in Escarpment Complex) old plants can attain 2 m and be up to 50 years old. It flowers mainly in November in the upper Blue Mountains, sets seed which ripens in March, and may be considered a facultative seeder.

Acknowledgements

It is a pleasure to record the considerable field assistance of Rae Druitt during this study. It is also a pleasure to record the assistance of a number of staff of the National Herbarium of NSW at the Royal Botanic Garden and Domain Trust in Sydney: Dr Peter Wilson, Clare Herscovitch, and Doug Benson were towers of strength in guiding my research for this paper. Andy Macqueen and Marianne Bate provided background maps for Figure 3. Arthur Henry of NSW National Parks and Wildlife Service at Blackheath provided vital information on fire histories. The sketch of Isohyets of Average Annual Rainfall is reproduced with permission from the Bureau of Meteorology. Finally, it is a pleasure to record the insightful comments of my referee, Roger Lembit.

References

Auld, Tony D, (1996), Ecology of the Fabaceae in the Sydney Region: fire, ants and the soil seedbank, *Cunninghamia* 4(4): 531–551.

Australia's Virtual Herbarium (AVH) http://avh.ala.org.au/search/#tab_simple Search

BMCC (1997) *Environmental Management Plan Stage 2: Local Environment Study: Study Area 2: Katoomba, Leura, Wentworth Falls* (Blue Mountains City Council, Katoomba NSW).

BMCC (2002) *Native vegetation mapping of Geographic Planning Areas 1 to 5. Blue Mountains City Council local government area* (Blue Mountains City Council, Katoomba NSW).

Burrows, G E (1995), Post-fire regeneration and growth of *Senecio garlandii* (Asteraceae) – a vulnerable plant of the South Western Slopes, NSW. *Cunninghamia* 4(1): 35–44.

Clarke, P J, Knox, K J E, Campbell, M L and Copeland, L M (2009) Post-fire recovery of woody plants in the New England Tableland Bioregion, *Cunninghamia* 11(2): 221–239.

Bureau of Meteorology (2015) http://www.bom.gov.au/nsw *Average Annual Rainfall: Sydney and Environs.*

Coleby, D (2015) *Epacris browniae* (Ericaceae), a newly discovered shrub from the Blue Mountains, New South Wales, Australia. *Telopea* 18: 67–72.

Eldridge, D J, and Bradstock, R A (1994) The effect of time since fire on the cover and composition of cryptogamic soil crusts on a eucalypt shrubland soil. *Cunninghamia* 3(3): 521–527.

Green, K. (2016) Dieback of *Nematolepis ovatifolia* (Rutaceae), an endemic shrub in the alpine- subalpine heaths of the Snowy Mountains, is facilitated by climate change. *Cunninghamia* 16: 1-9.

Keith, D (2004) *Ocean Shores to Desert Dunes: the Native Vegetation of New South Wales and the ACT*, Department of Environment and Conservation (NSW) ISBN 1 74137 920 2.

Knox, K J E and Clarke, P J, (2004), Fire response syndromes of shrubs in grassy woodlands in the New England Tableland Bioregion. *Cunninghamia* 8(3): 348–353.

Morgan, J W and Nield, C, (2011) Contrasting effects of fire severity on regeneration of the dominant woody species in two coastal plant communities at Wilsons Promontory, Victoria. *Cunninghamia* 12(1): 53–60.

PlantNET http://plantnet.rbgsyd.nsw.gov.au/cgi-bin/NSWfl.pl?page=nswfl&lvl=gn&name=Epacris

Manuscript accepted 1 June 2016

Date of Publication:
August 2016

Cunninghamia
A journal of plant ecology for eastern Australia

The Royal
Botanic Garden
Sydney

ISSN 0727-9620 (print) • ISSN 2200-405X (Online)

Population estimate of the parasitic herb *Thesium australe* (Santalaceae) in Booroolong Nature Reserve, Northern Tablelands, NSW

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Abstract: A survey of the population of the parasitic herb *Thesium australe* R.Br. (family Santalaceae) in Booroolong Nature Reserve, northwest of Armidale, found it was restricted to an eastern facing lower slope on metasediments, within regenerating grassy woodland of *Eucalyptus nova-anglica* H.Deane & Maiden (New England Peppermint) and a predominantly *Themeda triandra* Forssk. (Kangaroo Grass) and *Sorghum leiocladum* (Hack.) C.E.Hubb. (Native Sorghum) understorey. The population is in two clusters over a total area approximately 260 m long by 40 m wide and was estimated to be about 800 individuals at the time of survey (May 2014). Current threats include a maintenance trail, erosion of creek bank, stray cattle and sheep, rabbits and *Rubus anglocandicans* A.Newton (Blackberry) invasion. It is recommended that further searches be conducted and that monitoring occur on a regular basis using the permanently marked sites and methodology used in this survey.

***Cunninghamia* (2016) 16: 45-49**
doi: 10.7751/cunninghamia.2016.16.006

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Introduction

Thesium australe (family Santalaceae) is a green to yellow parasitic herb which grows to 40 cm tall (Figure 1). The stems are slender arising from a central base with opposite leaves. It is weakly erect to decumbent and is generally inconspicuous as it grows intertwined with grasses which it parasitises and is cryptic and easily missed. Although perennial, its above-ground parts often die back and may not be visible every year. *Thesium australe* is known to occur from south eastern Queensland south to Tasmania, though no extant populations are known from Tasmania. Initial observations indicated a preference for occurring in *Themeda triandra* Forssk. dominated grasslands on basaltic soils (Griffith 1996). These initial habitat preference concepts however lead many targeted surveys to falsely concentrate on areas dominated by *Themeda* on basalt in preference to others locations. Later surveys have found *Thesium* to be associated with various grass dominated understoreys, including exotic grasses, across a range of rock types (e.g. Hunter *et al.* 1999; Hunter 2000; Hunter 2003; Hunter 2011; Hunter *et al.* 2012). Within the New England Bioregion of New South Wales there are over 150 current and historical records of *Thesium australe* (Atlas of Living Australia; accessed 1/06/2016); however population sizes have rarely been recorded.

Thesium australe is a listed Vulnerable Species under the Federal *Environmental Protection and Biodiversity Conservation* Act (http://www.environment.gov.au/cgi-bin/sprat/public/publicspecies.pl?taxon_id=15202) and the New South Wales *Threatened Species Conservation* Act (http://www.environment.nsw.gov.au/ThreatenedSpeciesApp/profile.aspx?id=10802).

In April 2014 *Thesium australe* was discovered opportunistically during a vegetation mapping program conducted for the NSW Office of Environment and Heritage (Hunter 2014) within Booroolong Nature Reserve northwest of Armidale and an intensive investigation of its population size was consequently undertaken. This paper describes the size, habitat and potential threats to this population.

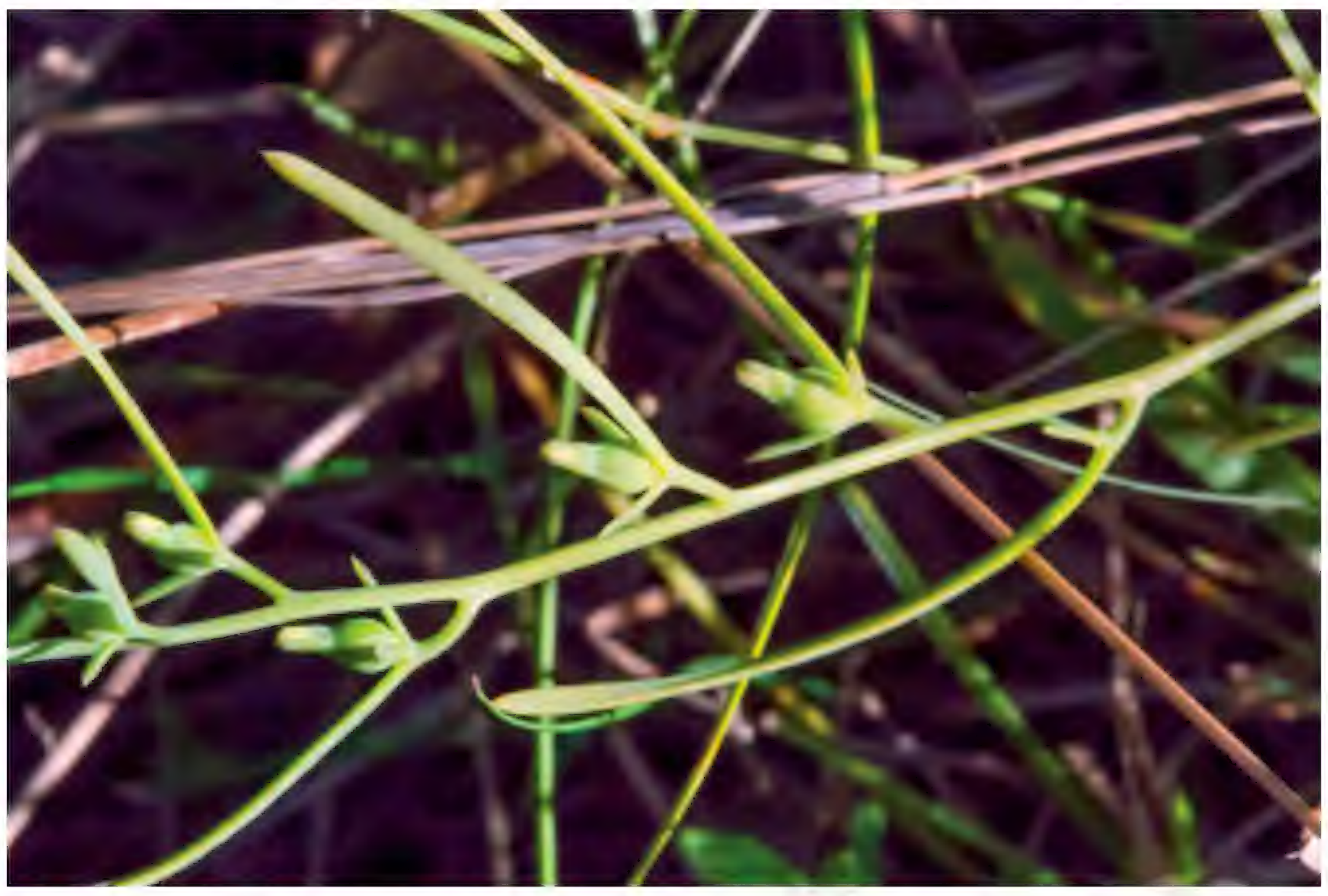

Figure 1. *Thesium australe* (family Santalaceae) is a green to yellow parasitic herb with slender stems arising from a central base with opposite leaves. It is generally inconspicuous as it grows intertwined with grasses which it parasitises.

Study location

Booroolong Nature Reserve is approximately 30 km by road northwest of Armidale, in the Northern Tablelands Botanical District and New England Tablelands Bioregion of New South Wales. The Reserve, dedicated in 1999, covers approximately 967 ha. Within the reserve *Thesium australe* was found associated with mid-reaches of a northerly facing valley on an eastern facing metasediment hill-slope between 1210 and 1220 m elevation, associated with *Eucalyptus nova-anglica* (New England Peppermint) regrowth and derived grasslands resulting from previous clearing of *Eucalyptus nova-anglica* Woodland.

Methods

The method chosen to assess the population incorporated a modified adaptive cluster design (Barker 2001, Christman & Lan 2001; Smith *et al.* 2004) with the following principal steps (see Figure 2):

1. A random 10 x 10 m quadrat is initially placed within the known population of *Thesium australe*.
2. Additional 10 x 10 m quadrats are then placed around all boundaries of the initial plot.
3. If an occurrence of *Thesium* is detected adaptive, 10 x 10 m plots are then added around that plot (8 in total).
4. If no *Thesium* is detected no further plots are placed around the negative plot (adaption is stopped).
5. If *Thesium* is detected in a plot it is permanently marked with surveyors pegs in all four corners and given an individual identification numbered and labelling in the southeastern corner.
6. Each positive plot is subdivided into five 2 x 10 m strips to assist in detection of plants.
7. The number of individual *Thesium* plants within each of the five strips is counted by two botanists independently.
8. After counting individual plots the botanists check their detection ability with each other by comparing numbers found within each 2 x 10 m strip.
9. If counts are significantly different (> 15%; arbitrarily chosen) the strips within the plot are resurveyed by both botanists individually until the difference is minimised.
10. When adaption was complete an adaptive line transect method, in which strips 20 m apart were walked, was used to search widely around the vicinity of the original population to capture any additional nearby clusters.
11. If additional populations were found an adaptive plot was placed and the process of 1-10 was repeated.

The survey was conducted from 2-5th May 2014 when *Thesium* is easier to see due to its yellowing colour at this time of year.

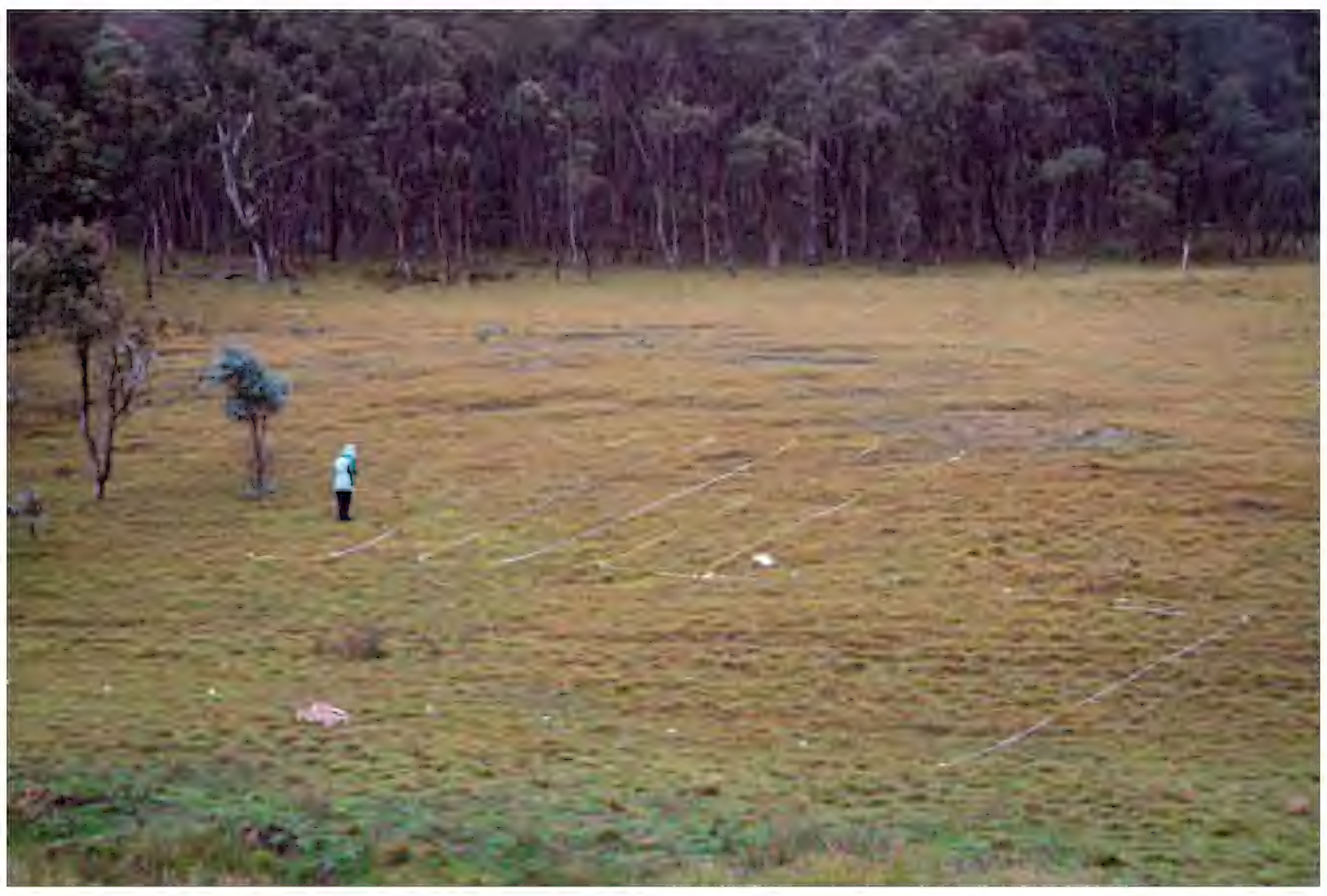

Figure 2. The site location of the Booroolong populations of *Thesium australe* showing the sampling layout.

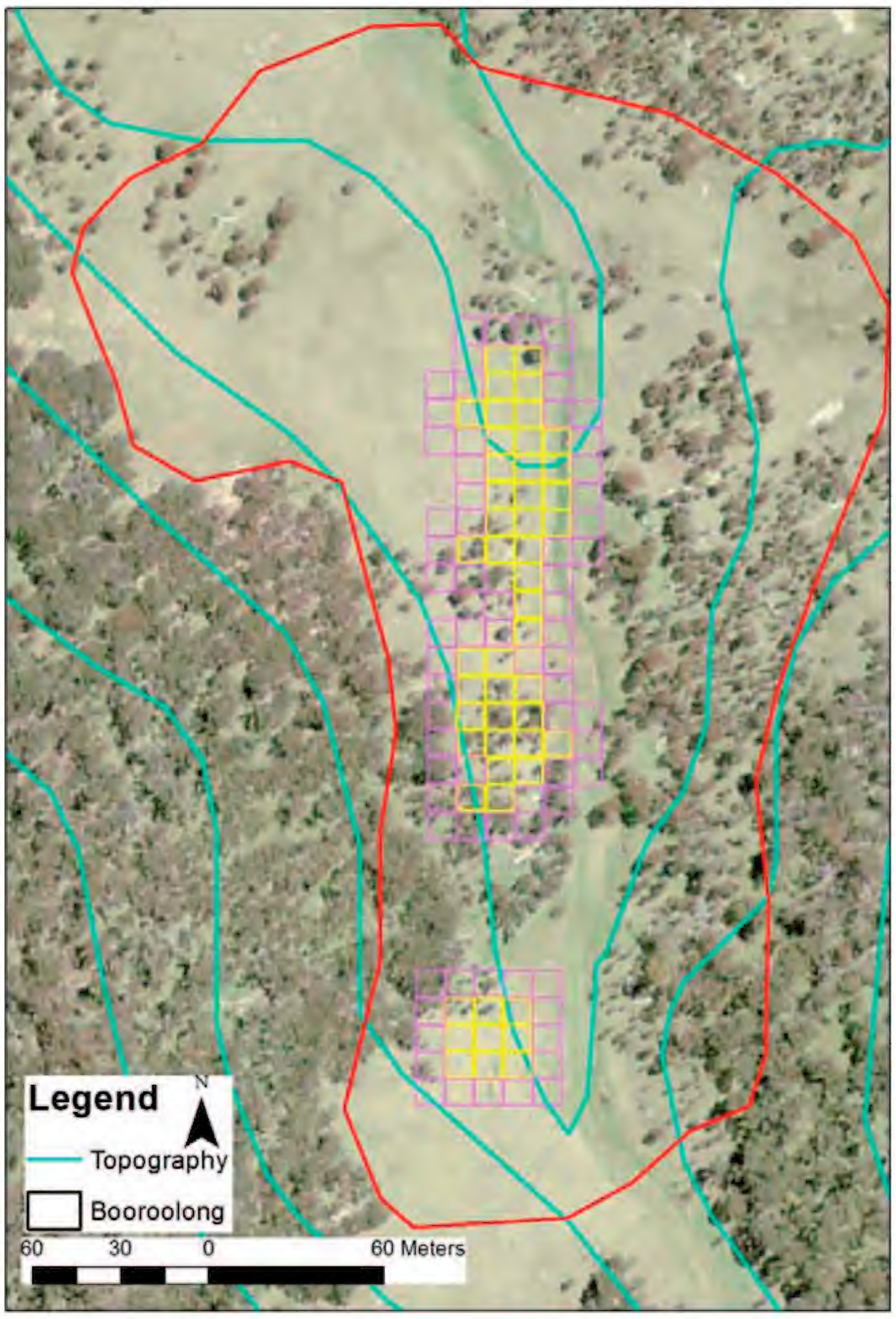

Figure 3. Placement of 10 x 10 m adaptive cluster design plots (squares) for the survey of *Thesium australe* and the area in which adaptive line transects were walked (red boundary) within Booroolong Nature Reserve. Positive subplots are indicated by yellow border and negative subplots by pink border.

Results

There were 52 permanently marked plots in total; 43 positive plots within the initial cluster and nine plots placed around a second cluster about 60 m further south (found during the adaptive line transect searches) (Figure 3). The results of the double count within each subplot and the five belt transects within them are given in Appendix 1. A total of 800 individuals of *Thesium* were found within the area searched. The highest number of individuals recorded within a 10 x 10 m subplot was 80 (0.8 plants/sqm) and the highest number within a 2 x 10 m strip was 28 (1.4 plants/sqm).

The *Thesium* clusters were confined to a 40 x 260 m area (Figure 3) and restricted to a narrow belt upslope from the valley floor and entirely on an eastern face. The clusters were intersected at their lower boundary by a management trail and an eroding creekline. Stray cattle and sheep are known within the vicinity and cow dung was found within the survey area. Macropods were observed in large numbers.

Though individual plants were found between vehicular wheeltracks the observed numbers decreased significantly on areas affected by vehicle movement. Individuals occurred along the tops of eroded creek faces indicating that some habitat has been lost through creek bank erosion. Rabbit burrows did not occur within the population but were frequent on the opposing western facing valley slope.

Discussion

The current (2014) population of *Thesium australe* within Booroolong Nature Reserve is substantial (ca. 800 individuals), and equivalent to the other known large extant populations (Griffith 1996; Cohn 2004). However, as the above ground parts of *Thesium* are not visible every year, regular surveys may be required to understand the species dynamics and avoid erroneous conclusions based on sudden decreases or increases in observed population size. Thickening of vegetation may impact on *Thesium australe* populations in a negative way by increasing the cover of the overstorey and changing the cover and abundance of understorey species on which *Thesium* may be parasitising. The population currently occurs in open derived native grassland and *Eucalyptus nova-anglica* woodland in various stages of recovery. It is highly likely that further expansion of *Eucalyptus nova-anglica* will occur across the open grassland areas containing the *Thesium* population. These permanently marked plots could easily be used to monitor the effects of the recovery of *Eucalyptus nova-anglica* woodland on the density and population size of *Thesium australe*.

Another threat to the population is the internal maintenance vehicle trail which should be diverted to avoid the current population clusters. In addition stabilisation of the creekbank may be of benefit, along with control of *Rubus anglocandicans* (Blackberry) and pest animals such as rabbits and stray livestock. It is likely that other *Thesium* clusters may be found in the modified woodlands and derived grasslands of Booroolong Nature Reserve and further investigation may be fruitful.

References

Barker, P. (2001) *A Technical Manual for Vegetation Monitoring*. (Resource Management & Conservation, Department of Primary Industries, Water & Environment: Hobart).

Christman, M.C. & Lan, F. (2001) Inverse adaptive cluster sampling. *Biometrics* 57: 1096-1105.

Cohn, J.S. (2004) Effects of slashing and burning on *Thesium australe* R.Br. (Santalaceae) in coastal grasslands of NSW. *Proceedings of the Linnaean Society of New South Wales* 125: 57-65.

Griffith, S.J. (1996) *Thesium australe*. Species Recovery Plan. (NSW National Parks & Wildlife Service: Hurstville).

Hunter, J.T. (2014) Vegetation and flora of Booroolong Nature Reserve. Unpublished report for the NSW Office of Environment and Heritage. DOI: 10.13140/RG.2.1.2823.0246.

Hunter, J.T. (2011) Vegetation and floristics of Little Llangothlin Nature Reserve. Unpublished report for the NSW Office of Environment and Heritage. DOI: 10.13140/RG.2.1.2788.8482.

Hunter, J.T. (2003) Vegetation of Arakoola Nature Reserve, North Western Slopes, New South Wales. *Cunninghamia* 8: 157-284.

Hunter, J.T. (2000) Vegetation and floristics of Kings Plains National Park. Unpublished report to the NSW National Parks & Wildlife Service. DOI: 10.13140/RG.2.1.1740.2724.

Hunter, J.T., Hawes, W. & Sonter, T. (2012) Uralla Shire Council Biodiversity Strategy: Arding, West Invergowrie, Kentucky & Rocky River. Unpublished Report to Uralla Shire Council. DOI: 10.13140/RG.2.1.3266.4169.

Hunter, J.T., Kingston, J. & Croft. P. (1999). Vegetation and floristics of Kwiambal National Park and surrounds, Ashford, New South Wales. *Cunninghamia* 6: 3890394.

Smith, Z. James, E.A. & Ladiges, P.Y. (2004) Morphological and genetic variation in the rare daisy *Olearia pannosa* subsp. *cardiophylla* (Asteraceae). *Muelleria* 20: 33-48.

Manuscript accepted 19 July 2016

Appendix 1: Raw counts of *Thesium australe* from both surveyors (A and B) of each of the five belt transects within each of the 52 plots.

Plot	1	2	3	4	5	Score
A	0	0	1	14	6	
B	0	0	1	12	6	
1 Total	**0**	**0**	**1**	**14**	**6**	**21**
A	0	0	0	0	1	
B	0	0	0	0	0	
2 Total	**0**	**0**	**0**	**0**	**1**	**1**
A	0	0	4	1	0	
B	0	0	5	1	0	
3 Total	**0**	**0**	**5**	**1**	**0**	**6**
A	1	0	0	0	0	
B	1	0	0	0	0	
4 Total	**1**	**0**	**0**	**0**	**0**	**1**
A	0	0	0	3	1	
B	0	0	0	2	1	
5 Total	**0**	**0**	**0**	**3**	**1**	**4**
A	2	4	4	3	7	
B	3	4	4	3	7	
6 Total	**3**	**4**	**4**	**3**	**7**	**21**
A	4	1	0	0	3	
B	4	1	0	1	2	
7 Total	**4**	**1**	**0**	**1**	**3**	**9**
A	0	1	0	0	1	
B	0	0	0	0	0	
8 Total	**0**	**1**	**0**	**0**	**1**	**2**
A	25	18	12	3	3	
B	19	19	14	3	6	
9 Total	**25**	**19**	**14**	**3**	**6**	**67**
A	19	17	12	9	12	
B	23	17	11	10	11	
10 Total	**23**	**17**	**12**	**10**	**12**	**74**
A	7	20	11	12	9	
B	8	19	15	12	9	
11 Total	**8**	**20**	**15**	**12**	**9**	**64**
A	6	7	4	1	0	
B	8	7	4	1	1	
12 Total	**8**	**7**	**4**	**1**	**1**	**21**
A	5	7	7	11	9	
B	5	8	5	12	10	
13 Total	**5**	**8**	**7**	**12**	**10**	**42**
A	1	0	0	1	2	
B	1	0	0	1	1	
14 Total	**1**	**0**	**0**	**1**	**2**	**4**
A	9	4	7	3	2	
B	11	4	3	3	4	
15 Total	**11**	**4**	**7**	**3**	**4**	**29**
A	7	5	3	0	5	
B	6	7	3	1	5	
16 Total	**7**	**7**	**3**	**1**	**5**	**23**
A	0	0	0	2	1	
B	0	0	0	2	1	
17 Total	**0**	**0**	**0**	**2**	**1**	**3**
A	11	4	2	2	4	
B	10	2	1	1	4	
18 Total	**11**	**4**	**2**	**2**	**4**	**23**
A	0	0	0	0	1	
B	0	0	0	0	1	
19 Total	**0**	**0**	**0**	**0**	**1**	**1**
A	3	1	0	0	2	
B	4	0	0	0	2	
20 Total	**4**	**1**	**0**	**0**	**2**	**7**
A	1	0	0	3	1	
B	0	0	0	3	1	
21 Total	**1**	**0**	**0**	**3**	**1**	**5**
A	0	1	0	1	0	
B	0	1	0	1	1	

Plot	**1**	**2**	**3**	**4**	**5**	**Score**
22 Total	**0**	**1**	**0**	**1**	**1**	**3**
A	0	6	2	6	0	
B	0	2	1	5	0	
23 Total	**0**	**6**	**2**	**6**	**0**	**14**
A	4	0	0	1	0	
B	5	1	1	2	0	
24 Total	**5**	**1**	**1**	**2**	**0**	**9**
A	0	0	2	9	15	
B	0	0	1	5	15	
25 Total	**0**	**0**	**2**	**9**	**15**	**26**
A	0	0	0	0	1	
B	0	0	0	1	1	
26 Total	**0**	**0**	**0**	**1**	**1**	**2**
A	1	4	3	0	2	
B	2	3	5	0	0	
27 Total	**2**	**4**	**5**	**0**	**2**	**13**
A	0	0	0	0	1	
B	2	0	0	0	0	
28 Total	**2**	**0**	**0**	**0**	**1**	**3**
A	0	0	0	0	5	
B	1	0	0	0	7	
29 Total	**1**	**0**	**0**	**0**	**7**	**8**
A	1	0	0	0	0	
B	1	0	0	0	1	
30 Total	**1**	**0**	**0**	**0**	**1**	**2**
A	1	1	6	1	2	
B	1	1	7	1	3	
31 Total	**1**	**1**	**7**	**1**	**3**	**13**
A	2	1	3	0	1	
B	2	1	3	1	2	
32 Total	**2**	**1**	**3**	**1**	**2**	**9**
A	1	2	1	0	0	
B	2	1	1	0	0	
33 Total	**2**	**2**	**1**	**0**	**0**	**5**
A	4	0	2	2	6	
B	2	1	0	5	5	
34 Total	**4**	**1**	**2**	**5**	**6**	**18**
A	0	1	0	1	2	
B	0	0	0	2	2	
35 Total	**0**	**1**	**0**	**2**	**2**	**5**
A	0	1	0	0	0	
B	0	0	0	0	0	
36 Total	**0**	**1**	**0**	**0**	**0**	**1**
A	0	3	0	2	1	
B	0	3	0	3	0	
37 Total	**0**	**3**	**0**	**3**	**1**	**7**
A	4	5	2	0	1	
B	4	5	2	0	1	
38 Total	**4**	**5**	**2**	**0**	**1**	**12**
A	0	0	4	0	0	
B	1	0	4	1	0	
39 Total	**1**	**0**	**4**	**1**	**0**	**6**
A	1	0	0	0	0	
B	0	0	0	0	0	
40 Total	**1**	**0**	**0**	**0**	**0**	**1**
A	0	1	0	1	1	
B	0	1	0	0	1	
41 Total	**0**	**1**	**0**	**1**	**1**	**3**
A	0	1	0	0	0	
B	0	0	0	0	0	
42 Total	**0**	**1**	**0**	**0**	**0**	**1**
A	0	0	0	0	1	
B	0	0	0	0	1	
43 Total	**0**	**0**	**0**	**0**	**1**	**1**
A	13	18	8	10	6	
B	15	21	13	12	8	
44 Total	**15**	**21**	**13**	**12**	**8**	**69**
A	1	1	1	0	0	
B	1	0	1	0	0	
45 Total	**1**	**1**	**1**	**0**	**0**	**3**
A	8	8	3	3	1	
B	8	8	3	3	1	
46 Total	**8**	**8**	**3**	**3**	**1**	**23**
A	0	0	2	0	1	
B	0	0	1	0	1	
47 Total	**0**	**0**	**2**	**0**	**1**	**3**
A	4	5	20	28	23	
B	4	5	20	27	23	
48 Total	**4**	**5**	**20**	**28**	**23**	**80**
A	6	0	0	0	0	
B	5	0	0	0	0	
49 Total	**6**	**0**	**0**	**0**	**0**	**6**
A	0	0	3	6	6	
B	0	0	3	7	5	
50 Total	**0**	**0**	**3**	**7**	**6**	**16**
A	0	0	0	1	5	
B	0	0	0	1	5	
51 Total	**0**	**0**	**0**	**1**	**5**	**6**
A	1	2	0	0	0	
B	1	2	0	0	0	
52 Total	**1**	**2**	**0**	**0**	**0**	**3**

Date of Publication:
August 2016

Cunninghamia
A journal of plant ecology for eastern Australia

The Royal
Botanic Garden
Sydney

ISSN 0727-9620 (print) • ISSN 2200-405X (Online)

Thomas Reedy 1842-1929: gardener for Sir William Macarthur and plant collector on the *Chevert* Expedition to New Guinea in 1875

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***Abstract*:** Thomas Reedy (1842-1929), gardener from 1854-1926 at Camden Park, the family estate of the Macarthurs in western Sydney was sent by Sir William Macarthur on the *Chevert* Expedition to New Guinea in 1875. He collected plants on islands off the Queensland coast; Cape Grenville; around the Somerset outpost on the tip of Cape York; on islands in the Torres Strait; and around two locations on the mainland of southern Papua New Guinea. Reedy sent or brought back 800-1000 living plants, in addition to an unknown number of seeds, and at least 157 dried specimens, the latter sent to Baron Ferdinand von Mueller in Melbourne. This study is focused on locating the dried plant specimens now held in herbaria and highlighting their significance.

Reedy is something of an enigma with little ever written about him. His initial has been presented erroneously since 1875 and has gone through various morphs including J, P, M and T; searches for Reedy best use all these initials or just his family name.

Keywords: *Chevert*, Sir William Macleay, Baron von Mueller, Camden Park

***Cunninghamia* (2016) 16: 51-63**
doi: 10.7751/cunninghamia.2016.16.007

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Thomas Reedy (1842–1929)

Thomas Reedy entered the employment of Sir William Macarthur in 1854 at the age of twelve, soon after arriving from Tipperary in Ireland (Anon. 1926), and was to stay in the employ of the Macarthur and Onslow families at Camden Park in western Sydney for his entire working life (1854-1926). He was held in high esteem, and at his retirement from his position as head gardener on February 20, 1926, at the age of 84 (Anon. 1926), he was offered a permanent home on the Camden Park estate. However, he chose to reside with his son James in Hurstville, Sydney. He passed away in January 1929 almost three years after his retirement; his funeral service was held at St. Pauls Church, Camden and he was buried in the Catholic Cemetery at Camden (Anon. 1929).

Reedy's life had been long associated with the historic gardens at Camden Park (34°05'18"S 150°43'23"E) at Camden in western Sydney where he had been Sir William Macarthur's "right hand man" and had held control over the orchard operations from their inception to his last day—he planted every tree by hand in the big orchard (Anon. 1926). Thus for 70 years Reedy was the unheralded gardener standing in the shadow of Macarthur. Sir William Macarthur (1800-1882) (a son of Captain John Macarthur, a noted figure in the very early history of Australia), was deeply involved in agriculture and horticulture; he is credited with introducing the camellia, cultivating fruit trees and vegetables, growing orchids in a hot house and, from 1843 publishing an annual catalogue of Camden Park's plants. He is also credited with pioneering winemaking in Australia, and was President of the Agricultural Society of New South Wales (Teale 2016). He was Commissioner at the International Exhibition in Paris 1855 where his collection of Australian woods was shown, and Executive Commissioner at London in 1862; his catalogue contained authentic Aboriginal names of trees (Maiden 1908; Teale 2016).

However this paper does not attempt to unravel Reedy's involvement at the gardens of Camden Park, nor his precise role in the horticultural pursuits of his employer Macarthur. My aim is to introduce Reedy and to shed light on the plants that he and his aides collected during the 1875 *Chevert* Expedition to tropical Queensland, Torres Strait and New Guinea; and in particular to identify as precisely as possible what plants were collected, where and when.

Methods

This study forms part of a larger study into the natural history collections of the Macleays (a family whose members were prominent in Australian entomological studies) and benefits from this deeper insight (e.g Fulton 2001; 2012; 2013; 2016a; 2016b; Fulton and Bialek 2015 and my unpublished notes). Dates were taken from my own unpublished analysis of the *Chevert* Expedition generated from the personal journal of Sir William Macleay (Macleay 1875a) and the private diary of Lawrence Hargrave, aeronautical pioneer and explorer (Hargrave 1874–1876).

The literature and herbarium records were searched for extant Reedy or Macarthur specimens: Macarthur specimens were only searched for in the area and times corresponding with the *Chevert* Expedition and following leads in Macarthur's 1875 *Sydney Morning Herald* newspaper article (Macarthur 1875). The following herbaria were searched by their own staff: Royal Botanic Gardens, Kew (K); Papua New Guinea National Herbarium (LAE); Singapore Herbarium (SING); Central Regional Centre —Botanical Survey of India (BSI); Herbarium Bogoriense (BO); National Herbarium of Victoria (MEL); National Herbarium of New South Wales (NSW); and Australia's Virtual Herbarium. Many herbaria stated that their databases were incomplete or could not be searched by a collector's name (searches by hand were limited without explicitly having the names of taxa). I did not search or press for more searches after this was established.

Locations for Reedy's specimen collections were deduced or taken directly from the following sources: the two diaries given above; the publications of Melbourne botanist Ferdinand von Mueller (1875–77; 1876a; 1876b 1878; 1888) and Adolf Engler (1910); the data from the sheets of surviving herbarium specimens held at MEL and NSW available on Australia's Virtual Herbarium; and Reedy's sequential specimen-numbering system (Reedy numbered his specimens in chronological order) which aided specimen placement at collecting sites. However, this was not a panacea to resolving collection locations, because many specimens or accounts of specimens no longer have Reedy's original number making his numbering system a fragmentary utility. The specimen with Reedy number 31 (MEL 2046542A) did not appear to follow Reedy's sequential pattern; perhaps at some stage the number, which is a very small cut-out piece of paper, has become separated from its original specimen and incorrectly returned to another specimen. Whatever happened, the number 31 is ignored in this assessment of collecting locations. Some errors were found in Mueller's publications. He erroneously transcribed Katau River to Ratau (see below) and he attributed some specimens erroneously to Baxter's River instead of the Ethel River (see below).

Reedy's Initials

Confusion has reigned over the initial of the given name for Thomas Reedy. Dowe (2007) highlighted that Reedy had been variously initialled J, M or P, although Dowe used the given name Thomas that had been published by Macarthur in 1875 (Macarthur 1875). The initials under consideration are given in square brackets before they are discussed. [J] The first culprit in the erroneous application of Reedy's initial was Mueller who published "J. Reedy" in his first and then subsequent issues of *Descriptive Notes on Papuan Plants* (Mueller 1875-77). This was probably a transcription error. Mueller may have had some difficulty deciphering Reedy's handwriting. In his second issue of *Descriptive Notes on Papuan Plants*, Mueller corrected the repeated transcription error of "Ratau River" with the following statement: "Katau-River; J. Reedy. The great watercourse, just mentioned, was incorrectly written in the first portion of this enumeration"

(Mueller 1876, p 25). [P] Of the fourteen herbarium sheets checked from the National Herbarium of Victoria (MEL) all carried Mueller's label with the name "Reedy" without initials. The single sheet seen from the National Herbarium of New South Wales (NSW–303018 *Eucalyptus papuana*) had "Patrick Reedy". The given name "Patrick" had been pencilled onto the sheet's MEL label (see Figure 2). In Joseph Maiden's *Records of Australian Botanists* under the heading *Macarthur, William (1800–1882)* appears the following: "He sent his gardener Mr. P. Reedy, to New Guinea" (Maiden 1908). Perhaps Maiden is the origin of the P initial? [M] The Council of Heads of Australasian Herbaria (CHAH) website (2007) quoted the botanical historian Norman Hall (specifically his book *Botanists of the Eucalypts*, 1978) to mistakenly state that Reedy, "who collected the type of *Eucalyptus papuana*" in 1875, was named Michael, referencing a Michael Reedy who was "the only Reedy whose death was recorded in New South Wales during the nineteenth century" (Hall 1978; CHAH 2007). However, Reedy's funeral and a short biography were reported in the *Camden News* and *The Sydney Morning Herald* (Anon. 1926; 1929). The assortment of names ascribed to Reedy has led to different documents giving a variety of different initials. Thus, searches for Reedy can be made using the initials J, P, M, or T, although only T will stand for Thomas.

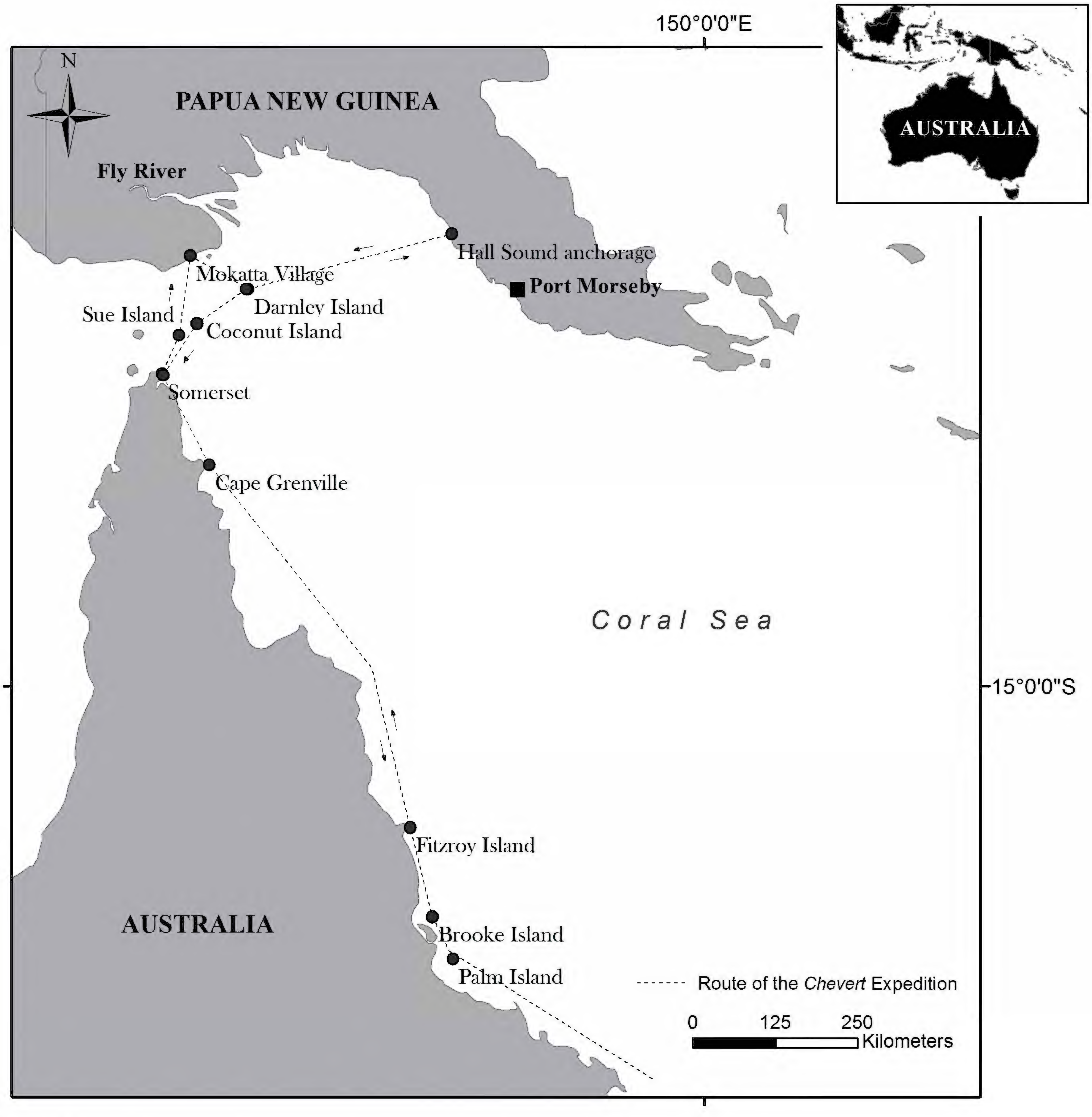


Figure 1. The 1875 voyage of the *Chevert* showing collecting points and the general direction of travel.

The *Chevert* Expedition

In May 1875, the barque *Chevert* departed Sydney bound for New Guinea, the first scientific expedition originating in Australia to leave for foreign shores (Figure 1). It was fully funded by William Macleay (1792-1865), the founder of the Macleay Museum. Along with a sailing crew, a team of zoological and ethnographical collectors made up the ship's complement. These included: Arthur Onslow; George Masters; Edward Spalding; John Brazier; William Petterd; Lawrence Hargrave and the ship's doctor, Dr James, who doubled as a collector and stuffer (Fulton 2012). The expedition was enormously successful adding approximately 1,000 birds, 800 fish, and many reptiles, mammals, insects, spiders, marine molluscs and ethnographic objects to Macleay Museum's collections (Macleay 1875b; Fletcher 1893; Fulton 2012).

However, this often-repeated story omits the plant collectors who accompanied these zoologists, and the indigenous people who often led the collectors to their specimens and helped collect them. From Camden Park Sir William Macarthur sent his gardener Reedy with assistant Dingwall (initials unknown) on the expedition, and had Felix Knight join them shortly before it concluded. Macarthur wrote to *The Sydney Morning Herald* less than two weeks after Macleay announced the conclusion of the expedition, to explain his collectors to an enquiring public. The majority of his article is included here because it is a valuable source of information.

> "Sir,—Being the person with the chief interest in the collections belonging to the vegetable kingdom made in the late expedition to New Guinea, will you oblige me by giving room for the following statement to correct misapprehension:—There was no "botanist," or, correctly speaking, "botanical collector" in the expedition, i.e., one capable of applying a scientific name or description to any new thing. Mr. Macleay very kindly gave me free quarters amongst his working staff on board the *Chevert* for three men—the chief of them is Mr Thomas Reedy, who from childhood has been employed in the garden at this place, for several years in full charge. I sent him at his earnest solicitation, and the other two, neither of them being even gardeners, but one, an excellent seaman, to assist Reedy in his collecting, and the expedition generally to the best of their ability. When I state that Reedy chiefly, by his own personal exertions and with the aid of the aborigines, has sent or brought back from 800 to 1000 living plants (not to mention seeds and dried specimens), most of them of considerable value, and the greater part in excellent condition, it will be admitted that my interest (Mr Macleay most liberally leaving them wholly at my disposal) could scarcely have been placed in better hands. But Reedy has no pretention to be called a "botanist," he is simply a most trusty, self-taught gardener, with great love of plants, very quick and observant, indefatigable in his vocation, and rarely, if ever, forgetting a plant he has once seen. Going, therefore, to an almost untrodden field, he has pretty well hit upon what was desirable to bring away. I am astonished that he has found opportunity to do so much, and to do it so well… The dried specimens of plants, though numerous, are by no means in such satisfactory condition as the living specimens. But, such as they are, I propose to send a complete collection, with such living plants as may seem desirable, to Dr Hooker of the Royal Gardens, Kew, and another to Baron F. Von Mueller, Melbourne. But the chief portion of the live plants generally, will probably pass into the hands of the Messrs. Veitch of Chelsea, reserving, however, specimens for my friends, and for the Botanical Gardens at Calcutta, Peradenya (Ceylon), Buitenzorg (Java), and Singapore, not forgetting our own establishments at Sydney and Brisbane" (Macarthur 1875).

Table 1. Collecting localities for Thomas Reedy and the *Chevert* Expedition in 1875

Macleay's name	Other names	Traditional owners		Latitude & Longitude	Dates
Australia					
Elizabeth Bay		Gadigal/Eora	♐	33°52'08.5"S 151°13'42.7"E	
Port Jackson	Sydney Harbour	Gadigal/Eora		33°51'17.8"S 151°14'23.7"E	
Vaucluse Bay		Gadigal/Eora	♐	33°50'58.2"S 151°16'19.8"E	
No. 2 Percy Island	Middle Percy Island	Guwinmal	♐	21°39'05.0"S 150°14'34.0"E	
Palm Island	Great Palm Island	Nyawaygi	♐	18°43'28.6"S 146°34'15.1"E	June 1
Brooke Island anchorage	Brook Islands	Wargamaygan	♐	18°09'41.9"S 146°12'50.0"E	
Garden Island		Wargamaygan		18°11'03.1"S 146°08'40.2"E	
Goold Island		Wargamaygan		18°09'56.2"S 146°10'12.8"E	

Macleay's name	**Other names**	**Traditional owners**		**Latitude & Longitude**	**Dates**
Brooke Island	North Island	Wargamaygan		18°08'43.0"S 146°17'16.7"E	June 4
North Barnard Island	Kent Island	Djirbalngan	♐	17°40'26.3"S 146°10'36.5"E	
Fitzroy Island		Yidinjdji	♐	16°55'38.1"S 145°59'04.8"E	June 5
Low and Woody Islands	Low Isles	Kuku-yalanji		16°22'52.5"S 145°33'40.1"E	
Turtle Reef	Turtle Group Reef	Guugu-yimidhirr		14°42'57.7"S 145°09'56.1"E	
Howick Island		Mutumui		14°30'08.3"S 144°58'25.0"E	
Barrow Island	North & South Barrow I.	Mutumui		14°20'40.8"S 144°39'02.6"E	
Flinders Island		Mutumui		14°10'37.3"S 144°15'08.0"E	
Cape Sidmouth (10 miles east of)		Umpila	♐	13°24'33.9"S 143°44'37.5"E	
Piper Island (6 miles south of)		Kuuku Ya'u	♐	12°14'38.3"S 143°13'05.8"E	
Cape Grenville		Wuthathi	♐	11°58'50.5"S 143°14'22.7"E	June12-17
Boydong Cays		Wuthathi		11°29'54.9"S 143°07'59.5"E	
Somerset		Yadhaigana‡		10°44'29.8"S 142°35'33.8"E	June 18-25 & Sept. 8-30
Shallow Bay		Yadhaigana‡	♐	10°43'41.0"S 142°34'31.9"E	
Blue Mud Bay	Mud Bay	Yadhaigana‡	♐	10°43'27.5"S 142°33'34.7"E	
Albany Island, Frederick Point		Muralag		10°42'56.1"S 142°35'06.0"E	
Evans Bay		Yadhaigana‡		10°42'23.4"S 142°32'31.7"E	
Thursday Island	Waiben	Muralag		10°34'46.4"S 142°13'06.9"E	
Sue Island	Warraber Islet	Kalaw Lagaw Ya		10°12'25.8"S 142°49'25.6"E	June 26 & July 26-27
Bet Island	Bara	Kalaw Lagaw Ya		10°08'45.7"S 142°49'10.7"E	
Coconut Island	Puruma (or Poruma) I.	Kalaw Kawaw Ya		10°02'59.6"S 143°04'09.2"E	Sept. 6
Long Island	Sassie	Kalaw Kawaw Ya		10°01'46.2"S 142°50'50.2"E	
Yam Island	Iama	Kalaw Kawaw Ya		9°54'09.6"S 142°46'30.0"E	
Dungeness Island	Zagai	Kalaw Kawaw Ya	♐	9°50'21.2"S 142°54'15.1"E	
Warrior Island	Tudu	Kalaw Kawaw Ya		9°48'11.5"S 142°58'28.9"E	
Yorke Islands	Masig	Kalaw Lagaw Ya		9°45'03.5"S 143°24'23.0"E	
Darnley Island	Erub Island	Erubam Le		9°34'50.8"S 143°46'16.9"E	July 30 to August 13
Nepean Island	Attagoy	Meriam Mir		9°34'05.9"S 143°39'22.5"E	
Mt Cornwallis Island	Dauan	Kalaw Kawaw Ya		9°25'09.9"S 142°32'03.3"E	

Macleay's name	Other names	Traditional owners	Latitude & Longitude	Dates
Poll Island	Guijar Islet	Kalaw Lagaw Ya	9°22′1.2″ S, 144°7′1.2″E	
Anchor Cay	Anchor Cay	uninhabited	9°21'43.0"S 144°05'56.0"E	
Bramble Cay		Erubam Le	9°08'31.1"S 143°52'29.9"E	
Papua New Guinea				
Katow River (mouth)	Binaturi River		9°08'23.8"S 142°57'19.3"E	
Mokatta Village			9°07'30.3"S 142°58'48.0"E	July 3-12
Hall Sound anchorage (from Hargrave's diary)		⚓	8°49'42.1"S 146°33'02.9"E	August 18 to Sept. 1
Hall Sound (south head)			8°51'14.2"S 146°33'58.5"E	August 24
Hall Sound (north head)			8°48'50.3"S 146°34'25.7"E	
Yule Island			8°49'06.3"S 146°32'01.2"E	August 18 to Sept. 1
Ethel River			8°48'51.2"S 146°36'06.7"E	August 25-26
Cape Possession			8°35'08.8"S 146°22'46.9"E	

Headings: Macleay's names follow nomenclature used in 1875 during the *Chevert* Expedition, which are commonly seen in the literature while Other names are the names used at the date of this publication. Traditional owners are taken from language groups given in Horton (1996). Anchorages are given by the anchor symbol. Dates are terrestrial collection dates in 1875 which are the known dates of the *Chevert's* collecting efforts and coincide with Reedy's known collections.

Chronology of collecting during the Chevert Expedition

Reedy visited the *Chevert* on April 9 during its refit before the expedition to assess and advise how best to carry the living plants he would collect (Macleay 1875a). The plants would need to be held in place when the *Chevert* pitched and rolled with the waves. A simple structure of wooden beams fixed across the hold was devised to stop the plant containers from moving (Macmillan 1957, p137). The *Chevert* was bound for New Guinea, though it made planned stops along the way including islands on the Great Barrier Reef, Cape Grenville and the outpost of Somerset near the tip of the Cape York Peninsula. Later, when analysing the material collected on the expedition, Mueller focused on the Torres Strait Islands and New Guinea for his *Descriptive Notes on Papuan Plants* (1875-77). He covered at least some of the Australian plants in his *Fragmenta phytographiæ Australiae*. However, Reedy sent him the material some of which is known to survive in Sydney (NSW) and Melbourne (MEL) herbaria.

The expedition's first scheduled stop was at Middle Percy Island on May 28, 1875 (Table 1; Figure 1). Macleay remarked in his personal journal, "In a very short time nearly every man in the ship the Captain excepted was on shore." However, though it is reasonable to assume that Reedy collected plants whenever he could, there are no surviving plant records from this location (extant material is missing from many locations). Great Palm Island was the second stop; there are four surviving Reedy specimens from this site including *Cryptocarya murrayi*, which is labelled number "1" and represents the first dried specimen collected (Table 2). Reedy was apparently busy that day, June 1, with Macleay writing in his journal, "Reedy's botanical collection was bulky and satisfactory, but nothing I believe new, which was scarcely to be expected." June 4, Brook Islands anchorage, Reedy and others went across to the island in conditions Macleay described as "rough and disagreeable" from an "an exposed situation" (Macleay June 4, 1875). A specimen of *Aglaia elaeagnoidea* survives. June 5, Fitzroy Island, Macleay noted, "Reedy, I believe has had more success than usual today, inasmuch as he believes he has got two new ferns" (Macleay June 5, 1875). Both ferns are missing, though a specimen of *Darlingia darlingiana* collected at Fitzroy Island survives in Melbourne (MEL). On the run to Cape Grenville, Reedy was sent ahead in the steam launch with other collectors to Barrow Island for "an hour or two of collecting" (Macleay June 9, 1875). No known specimens survive. Cape Grenville was the next collection location with at least nine known surviving specimens. It was a watering site and repairs to the *Chevert* were undertaken, resulting in a stay of five days, June 12–17. On June 12, when the passing mail steamer *Normanby* was hailed, Reedy sent "some casks etc of plants" back to Macarthur (Macleay June 12, 1875). From the Cape Grenville anchorage Reedy collected on the mainland and on adjacent islands—those close by and more distant (Macleay June 12-16, 1875).

Somerset, near the tip of Cape York, was the next collection location with the *Chevert* anchoring in Blue Mud Bay on

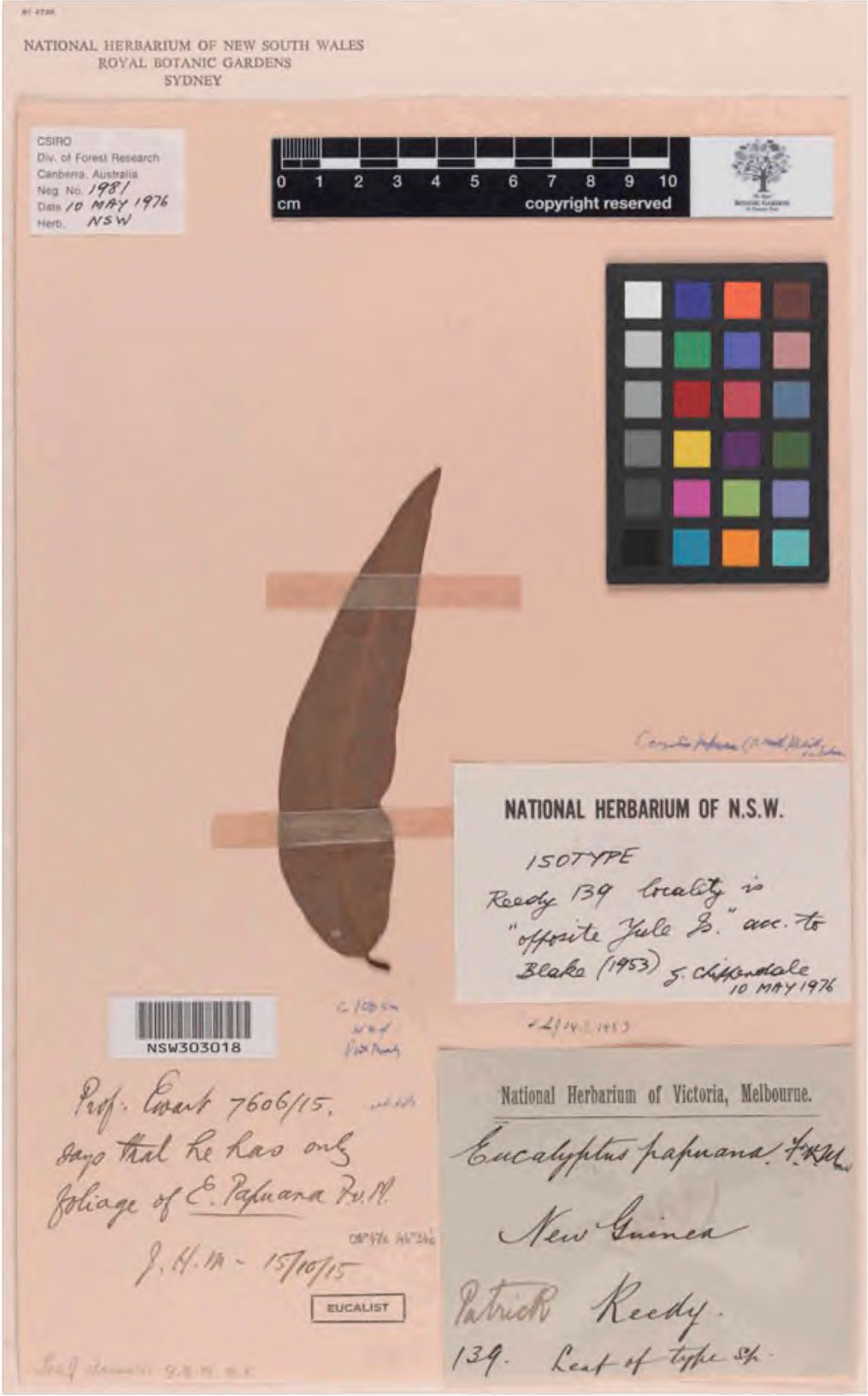
June 18. Reedy collected in this general area until June 25; at one point Macleay explicitly states that "Reedy and Dingwall went botanizing with a native guide… …Reedy, I believe also had some success" (Macleay June 21, 1875). On June 22 a group including Reedy collected at Evans Bay with Macleay stating, "Masters and Spalding got some good birds and Reedy some plants" (Macleay June 23, 1875). Four specimens survive from the Somerset area including an orchid *Dendrobium rigidum R.Br.* but precisely where these plants were collected is unknown. The *Chevert* stopped here again on the return journey, September 8-30, and Reedy collected what was the last known numbered specimen of the expedition here, number "157", *Rhodamnia fordii*.

Sue Island, in Torres Strait, was reached on June 26. A large party went ashore, of which Lawrence Hargrave wrote in his diary that some fruit dates were gathered while Macleay wrote, "everyone got something" (Hargrave 1874–1876; Macleay June 27, 1875). Mueller (1875–77) cited two collections from Sue Island, but only one of the specimens *Capparis quiniflora* DC. has been located in Melbourne (MEL 2085336A). The *Chevert* stopped at some Torres Strait Islands twice, on the outward bound journey and again on the return, although the return journey was rushed giving little time for collecting. They stopped at Sue Island on June 26 and one month later on July 26-27.

On the voyage from Somerset to New Guinea they had travelled more than half the distance in only two days, which included collecting stops at Sue and Warrior Islands. They then spent another five days winding their way through coral reefs before the *Chevert* finally anchored off the New Guinea mainland near the mouth of the Binaturi River on July 3. This river was known at the time as the Katau (spelt "Katow" by Macleay and incorrectly transcribed as "Ratau" by Mueller). Here Reedy collected at least 25 specimens either surviving or cited by Mueller with perhaps the most well-known of them being Macarthur's Palm *Ptychosperma macarthurii* (Dowe 2007), because it used around the world in horticulture. The collections here were restricted to around the village of Mokatta and up to 10 miles (16 km) inland along the Binaturi River. Collecting along the river would have been limited due to the presence of crocodiles and some hostility from the inland people. The village was situated on the coast near the beach with impenetrable swamps and the river behind limiting the range of collections (Fletcher 1893; Fletcher 1929; Fulton 2012). Mueller's publications do not differentiate between collections around the Mokatta Village and collections along the Binaturi River. The *Chevert* stayed at the Mokatta anchorage for ten days departing on July 12. Again they picked their way back though the reefs and did not attempt terrestrial collecting until they reached Dungeness Island on July 19. Thence stopping at Dungeness, Long, Bet, Sue, Coconut, Yorke and Darnley Islands. There is one extant specimen from Coconut Island; however, (based on Reedy's numbering system) this must have been collected on September 6 during the return journey. At Darnley Island Felix Knight, the third botanical collector sent along with supplies by Macarthur, joined the expedition. The expedition had a long stay at Darnley Island of 12 collecting days, from July 30 to August 13. Yet there are only two extant specimens that may have come from Darnley Island, although Mueller gave this location to six specimens. However, this number should have been five. One, *Macaranga tanarius*, Mueller wrote (as a transcription error), "Mainland opposite Darnley-Island and Yule-Island" (Mueller 1875-77, p 7). There is no mainland opposite Darnley Island whereas Yule Island sits adjacent the mainland of New Guinea. Mueller also wrote this the correct way with the "mainland opposite Yule Island and Darnley Island" (Mueller 1875-77, p 11). This transcription error must be read and understood this way.

Hall Sound was the last mainland site in New Guinea visited. From this anchorage they accessed Yule Island, different sites on the New Guinea mainland (north and south heads) and took an excursion up the Ethel River where type specimens of *Eucalyptus papuana* (now *Corymbia papuana*) and *Elaeocarpus arnhemicus* were collected by Reedy (Figure 2). They arrived on August 18 and departed on September 1, a stay of 14 collecting days. During that time it is clear that the indigenous people of the area helped in collecting plants. William Petterd, one of the expeditioners, described long canoes full of indigenous people attending the *Chevert* each day and eager to trade. The botanical collectors, Reedy, Dingwall and Knight in particular reaping a rich harvest of "beautiful crotons, dracaenas and other foliage plants, the natives bringing them off in large numbers, highly delighted with their newly discovered means of obtaining our treasures" (Petterd 1876). None of the genera *Croton* or *Dracaena* survive as herbarium collections, nor were any reported by Mueller.

Collecting began on Yule Island immediately after their arrival in Hall Sound and continued throughout, except on days when they collected on the mainland or during their excursion inland along the Ethel River. However, Macleay describes one day his collectors devoted almost solely to skinning and stuffing, an activity not required from plant collectors. Yet the plant collectors could have found ways of tending to their plants. The first collections on the mainland (abreast of Yule Island—north head) occurred on August 24 and were followed by collecting on August 27 and 29 giving three days in total. On the latter two days, parties collected about the southern headland of Hall Sound. A tentative exploration of the Ethel River was undertaken on August 21 without any attempt to collect. This was followed by an excursion over the two days, from August 25 to 26, which ventured inland along the Ethel River. It was during these two days that the holotype of *Eucalyptus papuana* was obtained. Macleay's personal journal (1875) and Petterd (1876) give accounts of a village situated on a hill and that such higher ground gave rise to Eucalypt woodland, which was distinctly different from the mangroves and marshy lowlands where most collecting was undertaken. Of the surviving specimens or descriptions there are: nine from the mainland; eight from the Ethel River and ten from Yule Island. Mueller (1877, p. 103) incorrectly referred to the Ethel River as "Baxter's River"; Macleay and thus Reedy never collected there. Mueller likely confused the Baxter and Ethel Rivers, because the *Chevert* Expedition was immediately followed by a cruise headed by the missionary Reverend Macfarlane.


NATIONAL HERBARIUM OF NEW SOUTH WALES
ROYAL BOTANIC GARDENS
SYDNEY
CSIRO
Div. of Forest Research
Canberra, Australia
Neg. No. 1981
Date 10 MAY 1976
Herb. NSW
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NATIONAL HERBARIUM OF N.S.W.
ISOTYPE
Reedy 139 locality is "opposite Yule Is." acc. to Blake (1953) J. Chippendale 10 MAY 1976
NSW303018
Prof. Ewart 7606/15. says that he has only foliage of E. Papuana F.v.M.
J. H. M. – 15/10/15
EUCALIST
National Herbarium of Victoria, Melbourne.
Eucalyptus papuana F.v.M.
New Guinea
Patrick Reedy.
139. Leaf of type sp.

Figure 2. Specimen of *Corymbia papuana* collected by Thomas Reedy (specimen collecting number 139) on the *Chevert* Expedition in 1875. Note the added name “Patrick” on the original Melbourne label. (National Herbarium of New South Wales image)

Table 2. Plant specimens collected by Thomas Reedy in 1875

Taxa	Source	Reedy's No.	Collection Location
Acanthaceae			
Acanthus ilicifolius L.	Mueller 1875, p 12.	s.n.	Binaturi River
Anacardiaceae			
Semecarpus	Mueller 1875, p 13 [†7]		
Semecarpus australiensis Engl.	MEL2245774A	3	Great Palm I.
Apocynaceae			
Dischidia major (Vahl) Merr.	*D. timorensis* Mueller 1875, p 12.	s.n.	
Dischidia nummularia R.Br.	Mueller 1875, p 12.	s.n.	PNG
Hoya australis R.Br. ex J. Traill	MEL710659A	s.n.	
Araliaceae			
Panax L.	Mueller 1875, p 13 [†7]		
Arecaceae			
Arenga microcarpa Becc.	MEL2067107A; Dowe 2007	48	Binaturi River
Caryota rumphiana Mart.	MEL2067113A; Dowe 2007	143	Ethel River
Licuala Thunb.	Mueller 1875, p 13 [†7] & Dowe 2007		
Ptychosperma macarthurii (H.Wendl. ex H.J.Veitch) H.Wendl. ex Hook.f.	MEL2067108A; Dowe 2007	36	Binaturi River
Aspleniaceae			
Asplenium laserpitifolium Lam.	Mueller 1875, p 15.	s.n.	Hall Sound mainland & Binaturi River
Asplenium polyodon G.Forst.	*A. falcatum* Mueller 1875, p 16.	s.n.	Binaturi River
Asteraceae			
Pluchea indica (L.) Less.	Mueller 1875, p 10.	s.n.	Binaturi River
Boraginaceae			
Heliotropium foertherianum Diane & Hilger	*Tournefortia argentea* Mueller 1875, p 11.	s.n.	Binaturi River, Yule I. & Torre Strait Is.
Heliotropium sarmentosum (Lam.) Craven	*T. sarmentosa* Mueller 1875, p 11.	s.n.	Hall Sound mainland & Darnley I.
Calophyllaceae			
Calophyllum L.	Mueller 1875, p 13 [†7]		
Capparaceae			
Capparis quiniflora DC.	MEL2085336A	72	Binaturi River & Sue I.
Casuarinaceae			
Casuarina equisetifolia L.	MEL2091863A	154	Coconut I.
Costaceae			
Tapeinochilos ananassae (Hassk.) K.Schum.	*T. pungens* Mueller 1875, p 13.	s.n.	Binaturi River
Cycadaceae			
Cycas L.	Mueller 1875, p 13 [†7]		
Elaeocarpaceae			
Elaeocarpus arnhemicus F.Muell.	MEL68069A type of *Elaeocarpus reedyi* F.Muell. [Mueller 1875, p6 & *E. reedyi* Mueller 1888, p 175.]	128	Yule I.
Elaeocarpus arnhemicus F.Muell.	MEL68068A; Holotype of *E. reedyi* F.Muell.	s.n.	Yule I.
Euphorbiaceae			
Macaranga tanarius (L.) Mull.Arg.	*Mappa tanaria* Mueller 1875, p 7.	s.n.	Hall Sound mainland & Darnley I.
Fabaceae			
Acacia Mill.	MEL2046562A	137	Ethel River
Acacia Mill.	Mueller 1875, p 13 [†7]		
Acacia holosericea A.Cunn. ex G.Don	MEL2046542A; Mueller 1877, p 103	31	Binaturi & Ethel Rivers

Taxa	Source	Reedy's No.	Collection Location
Archidendron grandiflorum (Sol. ex Benth.) I.C.Nielsen	MEL79994A	90	Yule I.
Inocarpus fagifer (Parkinson) Fosberg	MEL898A	93	Yule I.
Inocarpus fagifer (Parkinson) Fosberg	MEL2368394A	93	Yule I.
Intsia bijuga (Colebr.) Kuntze	MEL624741	s.n.	PNG
Lysiphyllum hookeri (F.Muell.) Pedley	MEL69818A	124	Ethel River
Tephrosia purpurea (L.) Pers.	MEL99333A	66	Hall Sound mainland & Darnley I.
Goodeniaceae			
Scaevola L. nom. cons.	Mueller 1875, p 13 †7		
Lamiaceae			
Clerodendrum inerme (L.) Gaertn.	*Clerodendron inerme* Mueller 1875, p 11.	s.n.	Binaturi River
Premna serratifolia L.	*Premna integrifolia* Mueller 1875, p 12.	s.n.	Binaturi River & Torre Strait Is.
Vitex trifolia L.	MEL97875A; Mueller 1875, p 11.	s.n.	Binaturi River
Lauraceae			
Cryptocarya murrayi F.Muell.	MEL623985A	1	Great Palm I.
Endiandra glauca R.Br.	MEL2091917A	145	Ethel River
Lecythidaceae			
Barringtonia asiatica (L.) Kurz	*B. speciosa* Mueller 1875, p 9.	s.n.	Binaturi River
Malvaceae			
Abutilon indicum (L.) Sweet	MEL649429; Mueller 1876, p 55		Darnley I.
Heritiera littoralis Aiton	MEL299961A	44	Binaturi River
Thespesia populneoides (Roxb.) Kostel.	MEL2222376A	17	Cape Grenville
Meliaceae			
Aglaia elaeagnoidea (A.Juss.) Benth.	MEL118600A	13	Cape Grenville
Aglaia elaeagnoidea (A.Juss.) Benth.	MEL593377A	29	Binaturi River
Aglaia elaeagnoidea (A.Juss.) Benth.	MEL118709A; [Macarthur given under collector]	s.n.	Brook I.
Dysoxylon Blume	Mueller 1875, p 13 †7		
Heritiera littoralis Aiton	*H. litoralis* Mueller 1875, p 6.	s.n.	Hall Sound mainland & Binaturi River
Menispermaceae			
Pachygone ovata (Poir.) Miers ex Hook.f. & Thomson	Engler 1910, p 246.		Binaturi River
Moraceae			
Ficus L.	Mueller 1875, p 13 †7		
Ficus prasinicarpa Elmer	MEL2088256A	53	Binaturi River
Ficus prasinicarpa Elmer	MEL2088258A	s.n.	
Ficus tinctoria G.Forst.	NSW303018	142	Ethel River
Myrtaceae			
Corymbia papuana (F.Muell.) K.D.Hill & L.A.S.Johnson	Holotype MEL; Iso. NSW; *Eucalyptus papuana* Mueller 1875 p 8.	139	Ethel River
Eucalyptus L'Her.	Mueller 1875, p 9. †1		
Eugenia L.	MEL2355171A	106	Yule I.
Rhodamnia fordii N.Snow	MEL2063940A	157	Somerset
Rhodomyrtus macrocarpa Benth.	MEL2194088A	12	Cape Grenville
Welchiodendron longivalve (F.Muell.) Peter G.Wilson & J.T.Waterh.	MEL2193313A	15	Cape Grenville
Oleaceae			
Jasminum didymum G.Forst.	MEL628125A	125	Hall Sound mainland

Taxa	Source	Reedy's No.	Collection Location
Orchidaceae			
Dendrobium rigidum R.Br.	MEL624409A	s.n.	Somerset & PNG
Spathoglottis plicata Blume	MEL625947A; *S. Pauline* Mueller 1876-77, p 64.	Unknown	Cape Grenville
Spathoglottis plicata Blume	MEL625946A; *S. Pauline* Mueller 1876-77, p 64.	19	Cape Grenville
Vappodes bigibba (Lindl. & Paxton) M.A.Clem. & D.L.Jones	MEL624057A	20	Cape Grenville
x Vappaculum x superbiens (Rchb.f.) M.A.Clem. & D.L.Jones	MEL 624455A; *Dendrobium superbiens* Mueller 1878-81, p 22.	21	Cape Grenville
x Vappaculum x superbiens (Rchb.f.) M.A.Clem. & D.L.Jones	MEL624456A; *D. superbiens* Mueller 1878-81, p 22.	s.n.	Somerset [Macarthur given under collector]
Pedaliaceae			
Josephinia imperatricis Vent.	MEL68551A	57	Binaturi River
Phyllanthaceae			
Phyllanthus amarus Schumach.	*Phyllanthus niruri* Mueller 1877, p 87.	s.n.	Darnley I.
Pittosporaceae			
Pittosporum Banks ex Gaertn.	Mueller 1875, p 13 [†7]		
Pittosporum ferrugineum Dryand. ex W.T.Aiton	MEL2112941A	69	Yule I.
Polypodiaceae			
Microsorum punctatum (L.) Copel.	*Polypodium punctatum* Mueller 1875, p 15.	s.n.	Hall Sound mainland
Pyrrosia longifolia (Burm.f.) C.V.Morton	MEL2147094A [via Macarthur]		Somerset
Proteaceae			
Darlingia darlingiana (F.Muell.) L.A.S.Johnson	MEL2170013A; *D. spectatissima* Mueller 1876-77, p 90.	8	Fitzroy I.
Grevillea pteridifolia Knight	MEL2175011A	18	Cape Grenville
Pteridaceae			
Adiantum aethiopicum L.	Mueller 1875, p 15.	s.n.	Hall Sound mainland
Pteris tripartita Sw.	Mueller 1875, p 16.	s.n.	Darnley I.
Pteris vittata L.	*Pteris longifolia* Mueller 1875, p 16.	s.n.	Yule I.
Rhamnaceae			
Colubrina asiatica (L.) Brongn.	Mueller 1875, p 7.	s.n.	Binaturi River & Sue I.
Rubiaceae			
Aidia racemosa (Cav.) Tirveng.	*Randia densiflora* Mueller 1876, p 25	s.n.	Binaturi River
Gardenia L.T.Ellis	Mueller 1875, p 13 [†7]		
Hydnophytum moseleyanum Becc.	*Hydnophytum formicarum* (?) Mueller 1875, p 10. [†4]		
Morinda citrifolia L. (?)	Mueller 1875, p 10. [†2]		
Myrmecodia echinata F.Muell. (?)	Mueller 1875, p 10. [†3]		
Premna callicarpa (?)	Mueller 1875, p 12 [†5]		
Scyphiphora hydrophylacea C.F.Gaertn.	Mueller 1875, p 10.	s.n.	Binaturi River
Tarenna dallachiana (F.Muell. ex Benth.) S.Moore	MEL1553931A	4	Great Palm I.
Santalaceae			
Exocarpos latifolius R.Br.	*Exocarpus latifolia* Mueller 1875, p 10.	s.n.	Binaturi River & Yule I.
Sapindaceae			
Guioa coriacea (Radlk.) Radlk.	*Cupania* Mueller 1875, p 13 [†7]		
Jagera pseudorhus (A.Rich.) Radlk.	MEL108736A	7	Great Palm I.

Taxa	Source	Reedy's No.	Collection Location
Sapotaceae			
Manilkara Adans.	*Achras* sp. Mueller 1875, p 13 †7		
Tectariaceae			
Christella dentata (Forssk.) Brownsey & Jermy	*Aspidium molle* Mueller 1875, p 15.	s.n.	Hall Sound mainland
Dicot. indet.			
	MEL2052002A	132	Ethel River
FUNGI			
Microxyphiella fuligo (Berk. & Desm.) Speg. 1918	Mueller 1876, p 82.	s.n.	Binaturi River

The available data dictates the taxonomic rank given; where possible scientific names and authorities follow CHAH (2015). The heading "Source" refers to the origin of the data used to identify a Reedy collection. Where applicable this is annotated with the name of the species used in that source, e.g., *Corymbia papuana* is given in its source as *Eucalyptus papuana* Mueller 1875 p 8. Collection locations were deduced in this study using the diaries of the *Chevert* expeditioners and the published literature, especially Mueller's *Descriptive Notes on Papuan Plants I* (1875). Reedy's numbering system follows the sequential order relating to the order that plants were collected—from 1 to 157. The maximum quantity of plants collected remains unknown. In the absence of a Reedy number, sheets in the National Herbarium of Victoria (MEL) were annotated "s.n." (*sine numero*, meaning without number).

The superscripts refer to notes in Mueller's 1875 publication relating to Reedy's specimens. Mueller felt that some material supplied by Reedy was insufficient to confidently name or describe—these notes are as follows: †1 leaves only seen, *E*. sp. found with *E*. papuana; similar to *E. platyphylla*; †2 leaves only, probably *M. citrifolia*; †3 leaves only, probably *Myrmecodia echinata*; †4 leaves only, probably *Hydnophytum*; †5 and several other Rubiaceous plants; †6 In Mueller's *Premna integrifolia* "The leaves of a *Callicarpa* are also contained in the collection."; †7 In Mueller's *Tapeinochilos pungens* "Reedy's collection contains also plants of the genera…[list given], but not in a state to determine their precise specific position".

Conclusion

Reedy's specimens now surviving in herbaria, and the specimens accounted for here, are only the dried preserved specimens collected by the expedition, and not the "800 to 1000 living plants" brought back (Macarthur 1875). Reedy's numbers suggest that about 157 (or a few more) dried specimens were collected given that number 157 was collected at Somerset on the return journey. Of the 157 specimens many are lost or missing. Macarthur was deeply involved in horticultural activities and Reedy's living specimens were collected with this in mind. Reedy probably did collect plants at every terrestrial stop, and the 800–1,000 living plants referred to by Macarthur were probably not sent to herbaria but to Camden Park, botanic gardens and horticulturalists. A search along these lines will probably find more history relating to Reedy's specimens.

With regard to biogeographical theories, Macleay (1875b) noted the striking similarity of the shared avifauna—not only between New Guinea and Australia, but between New Guinea and Micronesia. He also noted the shared mammalian fauna of New Guinea and Australia, being predominately marsupial (Macleay 1875b; Fulton 2012). Likewise Mueller developed similar biogeographical themes based on Reedy's collections noting shared genera and species: for example *Dischidia nummularia* and *Exocarpos latifolius* are species shared by Australia and New Guinea (Frodin 1990). Mueller (1875–77) opened his first plant description, that of *Capparis quiniflora*, with "The New Guinea plant cannot be distinguished from the Australian typical species." Yet the most striking example being *Corymbia papuana*, the type collected by Reedy near the Ethel River. Mueller (1875-77) in opening his *Descriptive Notes on Papuan Plants* described New Guinea as one of the largest islands on the globe, which rivalled Britain in extent yet remained poorly known. He acknowledged that exploration would gradually withdraw the veil by which it has so long been concealed. Reedy's specimens were among the first from southern New Guinea to be examined by Mueller and were important in opening a narrative on the flora of the region. Mueller subsequently named *Elaeocarpus reedyi* in commemoration of Reedy's contribution, but alas it was a synonym of *Elaeocarpus arnhemicus* F.Muell. (Mueller 1888, p 175).

Acknowledgements

I thank Pina Milne (MEL) for accessing herbarium specimens and promptly answering my queries, which were essential in the preparation of this paper. Special thanks to Jutta Beher (UQ) for making the map of the *Chevert's* voyage. I also thank John Dowe (JCU) and Pina Milne for their comments on a draft manuscript. I thank the National Herbarium of New South Wales for use of Figure 2. I acknowledge the many traditional owners of the places mentioned in this text—people who were actively involved in collecting with the *Chevert* Expedition and without whom there would be much less to discuss, they include the Nyawaygi, Wargamaygan, Yidinjdji, Wuthathi, Yadhaigana, Kalaw Kawaw Ya, Kalaw Lagaw Ya, and Erubam Le people, and the people of Papua New Guinea.

References

Anonymous (1926) Untitled. *The Camden News* Thursday, February 25, 1926: p 4.

Anonymous (1929) FUNERALS. REEDY. *The Sydney Morning Herald* Saturday, January 12, 1929: p 15.

CHAH (Council of Heads of Australasian Herbaria). (2007) Biographical Notes: Reedy (fl. before 1875) possibly Reedy, Michael (c. 1851 - 1890). https://www.anbg.gov.au/biography/reedy-michael.html (Viewed February 24, 2016).

Council of Heads of Australasian Herbaria. (2015) Australian Plant Census Online. http://biodiversity.org.au/nsl/services/apc (Viewed March 10, 2016).

Dowe, J. L. (2007) *Ptychosperma macarthurii*: Discovery, Horticulture and Taxonomy. *Palms* 51: 85–96.

Engler, A. (1910) *Das Pflanzenreich: regni vegetablilis conspectus*. Verlag von Wilhelm Engelmann, Leipzig.

Fletcher, J. J. (1893) *The Macleay Memorial Volume*. Linnean Society of New South Wales, Sydney.

Fletcher, J. J. (1929) The Society's Heritage from the Macleays. Part ii. *Proceedings of the Linnean Society of New South Wales* 54: 185–272.

Frodin, D. G. (1990) Explorers, Institutions and Outside Influences: Botany North of Thursday. In: Short, P. S. (ed.) *History of Systematic Botany in Australasia* pp. 193–215. Australian Systematic Botany Society, South Yarra.

Fulton, G. R. & Bialek, P. (2015) Translation to English of Speeches Given in French to Honour William Macleay at a Picnic of the Linnean Society, 1st May 1875. *Proceedings of the Linnaean Society of New South Wales* 137: 13–16.

Fulton, G. R. (2001) Threatened and extinct bird specimens held in the Macleay Museum, University of Sydney, Australia. *The Bulletin of the British Ornithologists´ Club* 121: 39–49.

Fulton, G. R. (2012) Alexander, William Sharp, and William John Macleay: Their Ornithology and Museum. In: W. E. Davis, Jr., H. F. Recher, W. E. Boles and J. A. Jackson. (Eds.) *Contributions to the History of Australasian Ornithology Vol. 2* pp. 327–393. Nuttall Ornithological Club, Cambridge, Massachusetts.

Fulton, G. R. (2013) Dodo *Raphus cucullatus* in the Macleay Museum, The University of Sydney, Australia. *Archives of Natural History* 40: 171–174.

Fulton, G. R. 2016a. Bramble Cay Melomys *Melomys rubicola* Thomas 1924: specimens in the Macleay Museum. *Proceedings of the Linnaean Society of New South Wales* 138: 59–60.

Fulton, G. R. 2016b. New Information about the Holotype, in the Macleay Museum, of the Allied Rock-wallaby *Petrogale assimilis* Ramsay, 1877 (Marsupialia, Macropodidae). *Proceedings of the Linnaean Society of New South Wales* 138: 57–58.

Hall, N. (1978) *Botanists of the Eucalypts*. Commonwealth Scientific and Industrial Research Organisation, Melbourne.

Hargrave, L. (1874-1876) Diary F. Lawrence Hargrave, Australia/Papua New Guinea, 25 January 1872–2 February 1876. [Powerhouse Museum].

Horton, D. R. (1996) *Indigenous Language Map.* Aboriginal Studies Press, AIATSIS and Auslig/Sinclair, Knight, Merz. http://www.abc.net.au/indigenous/map/default.htm (Viewed February 3, 2016).

Macarthur, W. (1875) Expedition to New Guinea. To the Editor of the Herald. *The Sydney Morning Herald* Wednesday, October 20, 1875: p 6.

Macleay, W. (1875a) William John Macleay's personal journal. Transcribed by D. S. Horning 1995. Macleay Museum, University of Sydney, Sydney. [Macleay's original version is held in the Mitchell Library, Sydney.]

Macleay, W. (1875b) Notes on the zoological collections made in Torres Straits and New Guinea during the cruise of the *Chevert*. *Proceedings of the Linnean Society of New South Wales* 1: 36–40.

Macmillan, D. S. (1957). A squatter went to sea: the story of Sir William Macleay's New Guinea expedition (1875) and his life in Sydney. Currawong Publishing Co., Sydney.

Maiden, J. H. (1908) Records of Australian Botanists— (a) General, (b) New South Wales: Macarthur, William (1800—1822). *Journal and Proceedings of the Royal Society of New South Wales* 42: 56–132 [111-112].

Mueller, F. (1875-77) *Descriptive Notes on Papuan Plants* I-V: 1-119. George Skinner, Melbourne.

Mueller, F. (1876a) Orchidaeae *Spathoglottis Pauline Fragmenta phytographiæ Australiae* 10: 64-65.

Mueller, F. (1876b) Proteaceae;*Darlingia spectatissima Fragmenta phytographiæ Australiae* 10: 90.

Mueller, F. (1878) Orchidaeae *Dendrobium superbiens. Fragmenta phytographiæ Australiae* 11: 22.

Mueller, F. (1888) Two Hitherto Unrecorded Plants from New Guinea. *Transactions and Proceedings of the Royal Society of Victoria* 24: 174–175.

Petterd, W. F. (1876) New Guinea. [No. 2.] Hall Sound. *The Mercury* Tuesday April 26, 1876: p 3.

Teale, R. (2016) Macarthur, Sir William (1800–1882). Australian Dictionary of Biography, National Centre of Biography, Australian National University, http://adb.anu.edu.au/biography/macarthur-sir-william-4061/text6469 (Viewed February 22, 2016).

Manuscript accepted 2 August 2016

Date of Publication:
September 2016

Cunninghamia
A journal of plant ecology for eastern Australia

The Royal
Botanic Garden
Sydney

ISSN 0727-9620 (print) • ISSN 2200-405X (Online)

Vegetation of *Naree* and *Yantabulla* stations on the Cuttaburra Creek, Far North Western Plains, New South Wales

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Abstract: *Naree* and *Yantabulla* stations (31,990 ha) are found 60 km south-east of Hungerford and 112 km north-west of Bourke, New South Wales (lat. 29° 55'S; long. 150°37'N). The properties occur on the Cuttaburra Creek within the Mulga Lands Bioregion. We describe the vegetation assemblages found on these properties within three hierarchical levels (Group, Alliance & Association). Vegetation levels are defined based on flexible UPGMA analysis of cover-abundance scores of all vascular plant taxa. These vegetation units are mapped based on extensive ground truthing, SPOT5 imagery interpretation and substrate. Three 'Group' level vegetation types are described: Mulga Complex, Shrublands Complex and Floodplain Wetlands Complex. Within these Groups nine 'Alliances' are described: Rat's tail Couch – Lovegrass Grasslands, Canegrass Grasslands, Lignum – Glinus Shrublands, Coolibah – Black Box Woodlands, Turpentine – Button Grass – Windmill Grass Shrublands, Turpentine – Hop Bush – Kerosene Grass shrublands and Mulga Shrublands. Sixteen 'Associations' are described 1) Mulga – Poplar Box Shrubland, 2) Mulga – Poplar Box – Bastard Mulga Shrubland, 3) Turpentine – Hop Bush – Senna Shrubland, 4) Turpentine – Elegant Wattle – Boobialla Shrubland, 5) Turpentine – Hop Bush – Daisy Bush Shrubland, 5) Belah – Rosewood – Turpentine Bush Shrubland, 6) Belah – Rosewood – Turpentine Bush Shrubland, 7) Ironwood – Leopardwood – Supplejack Shrubland, 8) Yapunyah – Black Box – River Cooba Woodland, 9) Coolibah – River Cooba – Yapunyah Woodland, 10) Rat's tail Couch – Lovegrass – Fairy Grass Grassland and Herbfield, 11) Rat's tail Couch – Lovegrass – Purslane Grassland and Herbfield, 12) Darling Pratia – Rat's tail Couch – Spike Rush Herbfield, 13) Canegrass Grassland, 14) Glinus – Groundsel – Lignum Herbfield, 15) Poplar Box – Mulga – Coolibah Woodland and 16) Black Box Woodland. In total 355 vascular plant taxa were found of which 6% were considered exotic in origin. A population of *Dentella minutissima*; a species listed as threatened (endangered) under the New South Wales *Threatened Species Conservation Act* 1995 was found. A summary of select structural and habitat attributes within Alliances is also presented.

Key words: mapping, conservation, floristics, floodplain, woodland, mulga lands, wetlands.

***Cunninghamia* (2016) 16: 65–100**
doi:10.7751/cunninghamia.2016.16.008

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Introduction

Naree and *Yantabulla* are adjoining former sheep and cattle stations (lat. 29° 55'S; long. 150°37'N) located along the Cuttaburra Creek which flows into Yantabulla Swamp and eventually into the Paroo River. The Paroo is a major tributary of the Murray Darling System (Figure 1). The properties lie in the Mulga Lands Bioregion, 150 km north-west of Bourke in north-west New South Wales. A former pastoral property, *Naree* Station (15,000 ha) was purchased by Bush Heritage Australia in 2012 (http://www.bushheritage.org.au/places-we-protect/new-south-wales/naree). In 2015 the southern neighbouring pastoral property of *Yantabulla* Station (16,000 ha) was purchased by South Endeavour Trust (http://www.southendeavour.com.au/). Both properties are currently managed by Bush Heritage Australia. Both properties have been purchased for conservation purposes but were grazed in the past with sheep and cattle, *Naree* being destocked in 2012 and *Yantabulla* in 2015.

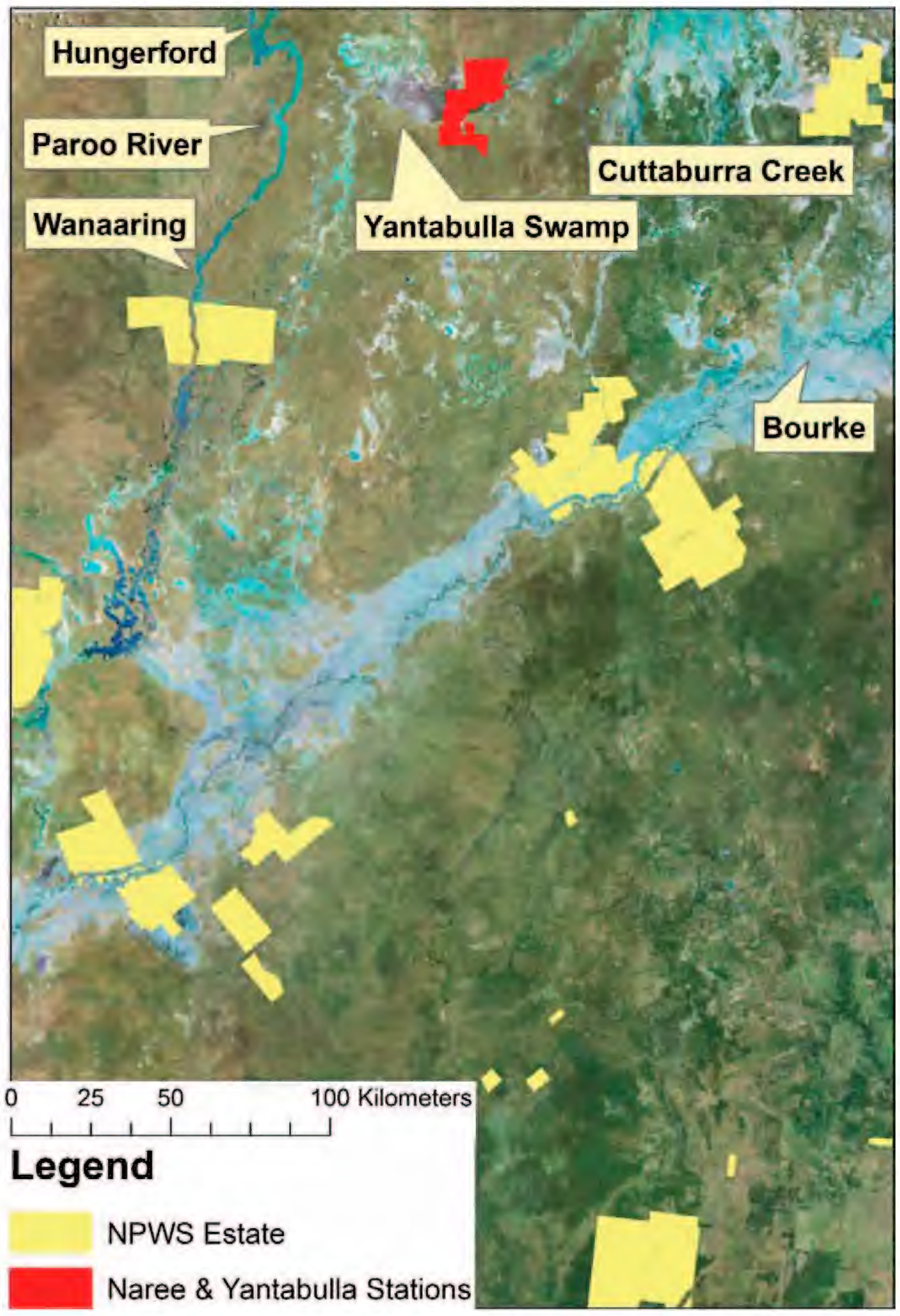

Fig. 1. Location of *Naree* and *Yantabulla* Stations and other nearby National Park Estate reserves.

These properties occur over a variety of landscapes including floodplains of grey to black self-mulching cracking clay soils, wetlands of various sizes, soil types and inundation durations, aeolian dunes and ridge country of red to red brown clays. Altitude ranges from around 120 to 150 m above sea level. Climatic instability is a constant feature of arid and semi-arid areas of western New South Wales and is generally more unpredictable than in similar climatic zones elsewhere in the world leading to irregular resource and productivity pulsing (Westoby, 1988; Morghan *et al.* 2016).

This paper provides part of the results of a flora survey conducted to acquire baseline data for the future management of *Naree* and *Yantabulla* conservation areas, to construct a map of the floristic vegetation assemblages and the occurrence of rare taxa and communities. The data is to be used in conjunction with ongoing monitoring to assess change and provide feedback on management outcomes.

Methods

Sample site placement

A total of 208 full floristic 20 x 20 m plots were surveyed for vascular plants scored using the Braun-Blanquet six point cover abundance scale (Westhoff & Maarel 1978). In addition, 233 rapid survey plots (RPD) recording only dominant species of each stratum were also placed. Thirty-four of the full floristic plots were originally permanently marked during initial post purchase surveys conducted by Bush Heritage within Naree in 2013. These original plots were re-surveyed by the authors in June of 2014; all other plots were surveyed in April 2015. It is acknowledged that due to the ephemerality of much of the herbaceous flora that some variation will have been missed due to the timing of our surveys. Thirty-three plots were randomly placed using ArcGIS (10.1) across the properties with a minimum distance between of 500 m and permanently marked. All other plots were placed using a stratified random methodology based on major landscape types. All permanently marked full floristic survey plots (79 in total) were revisited in April 2016. At each location information was gathered on location and altitude with reference to geographical positioning system (GPS; Garman Map 62s; Garmin International, Olathe, KS, USA) along with physiography, soil drainage, colour and depth.

Habitat data

Fifty-five permanently marked sites (marked in each of the four corners) were chosen for further investigation of habitat and structural attributes. Within these sites projected foliage cover was recorded every 5 m along a 50 m transect along one side of the plot (extending out a further 30 m) starting at the south-eastern corner. Within the extended 20 x 50 m plot the cumulative length of all logs, small end diameter over 10 cm width, was recorded along with the number of log hollows. The identity and number of all shrubs greater than 1 m in height was recorded within the 20 x 20 m plot and the identity and number of all shrubs below 1 m was recorded within a 5 x 5 m subplot within the south-east corner. At the 2-2.5 m mark from each corner post a 50 x 50 cm subplot was placed and all litter collected (a total of 8 sub-plots per plot). Pieces of wood less than 1 cm diameter were included as litter. All litter sub-plots were combined and weighed using an OHAUS Pioneer balance in grams to two decimal places. Tree density was measured using the method employed by Hunter (2013; 2015ab) whereby a random tree with a minimum diameter at breast height (130 cm) (DBH) of 5 cm was chosen as a central tree within each randomly placed plot. If no stem >5 cm DBH occurred within the 20 x 50 m plot this process was not followed. From this tree 15 of the closest live trees of over 5 cm DBH (130 cm) were measured (16 live trees inclusive of the central tree) and the DBH of every stem >5 cm DBH was recorded separately for each individual. Diameters were measured using a Haglof diameter clamp to the nearest 0.5 cm. All dead trees within the radius of the furthest live tree were measured but did not count towards the total minimum of 16 live trees. The size of these tree plots was unbounded and dependent on the distance to the furthest tree recorded. For each tree the identity of the species and distance to the first tree (meters) using a Kinchrome 150 mm measuring wheel were recorded. The size of each site was calculated as the area of the circle whose radius was the distance from the central tree to the furthest tree which enclosed all trees previously recorded. The height and number of tree hollows above 1 m from the ground (opening of >5 cm which projected into the stem) was recorded for each tree.

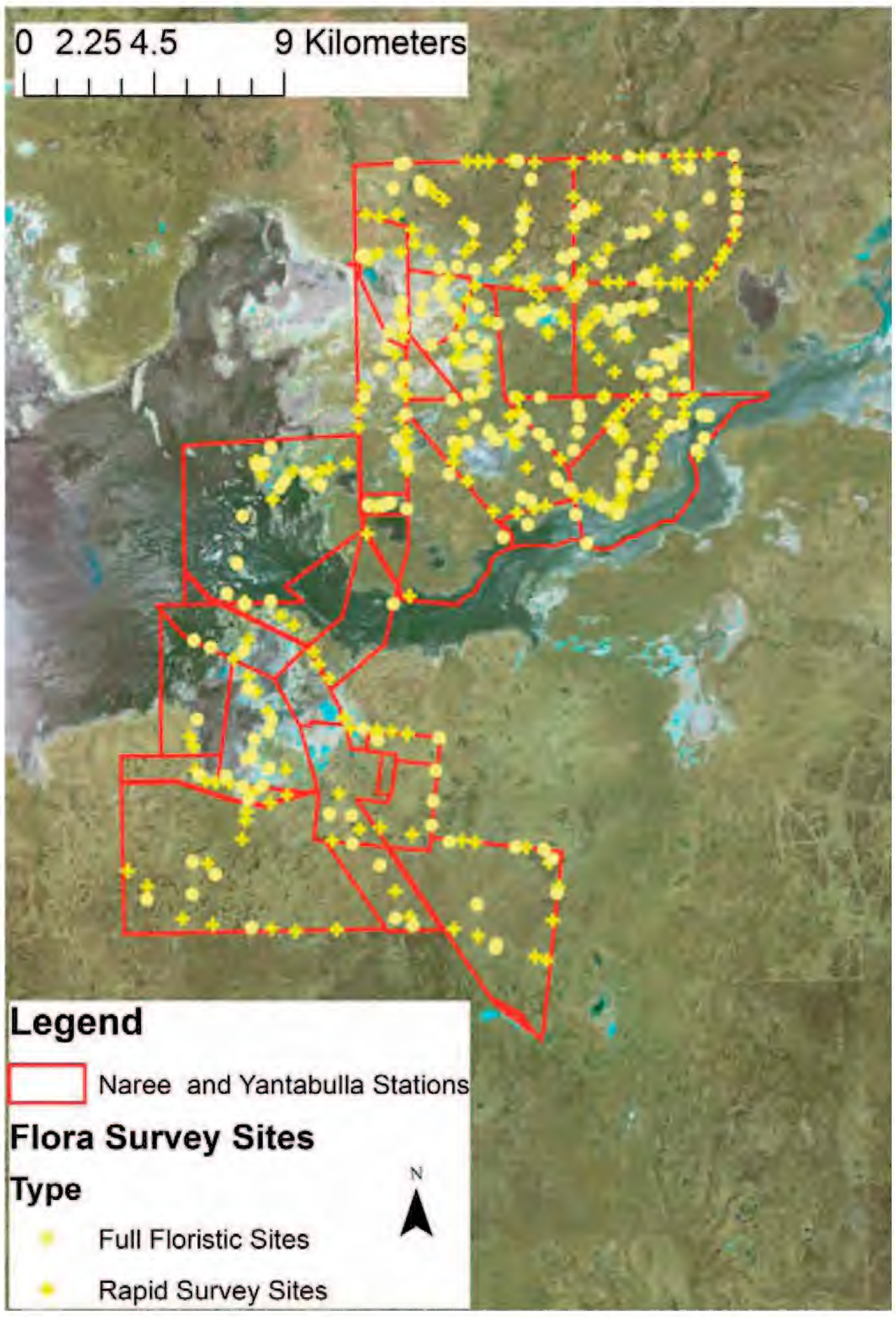

Fig. 2. Placement of full floristic and rapid survey sites across *Naree* and *Yantabulla* Stations.

Statistical analysis

Analysis and data exploration were performed using options available in the PATN 3.2 Package (Belbin 1995a, b). For final presentation of results all species and their relative abundance scores were used and the analysis performed using Kulczynski association measure which is recommended for ecological applications (Belbin 1995a, b) along with flexible Unweighted Pair Group arithmetic Averaging (UPGMA) and the default PATN settings. Each plot (Full floristic and RPD) were assigned to three vegetation classification levels (Group, Alliance, Association) according to the definitions of EcoVeg (Faber-Langedoen *et al.* 2014) based on the results of the statistical analysis of the full floristic survey plot data. Within the EcoVeg criteria a group comprises a set of diagnostic plant species and growth forms that reflect regional mesoclimate, geology, substrates, hydrology and disturbance regimes (Faber-Langedoen *et al.* 2014). The plots and their assigned floristic units were re-projected onto SPOT5 imagery using ArcGIS (10.1) software. The plots, the notes taken on traverses, structural characteristics seen on imagery along with topological information were used to delineate vegetation polygons. This methodology follows the guidelines for vegetation mapping provided within the Native Vegetation Interim Standard (Sivertsen 2009). EstimateS 8.2 (Colwell 2006) was used to produce a rarefaction curve based on 1000 randomisations to calculate the potential number of species within the study area.

Results

In total sixteen Associations are described within nine Alliances and three Groups. Associations have been defined at a dissimilarity level of 0.9; a summary of association relationships is given in the dendrogram (Fig. 3). Mapping of Groups is given in Figure 4 and Associations in Figure 5. Over the survey period and based on opportunistic recordings of other surveyors a total of 355 vascular plant taxa have been found within the two properties. These 355 taxa were from 52 Families and 179 Genera. A total of 22 (6%) of the flora is exotic in origin. The cumulative number of species recorded (355) from all survey periods is higher than the predicted number (350) but within 95% confidence (upper limit of 410) based on the turnover during 2015 survey period (Fig. 7). Species density (species per plot) was highly variable from as few as one to 48 taxa (Table 1). Association 6: *Eragrostis australasica* had the lowest average number of species per site (6) with Association 1: *Acacia aneura – Eucalyptus populnea* containing an average of 25 taxa (Table 1). All taxa and their occurrence within associations are given within the Appendix. A total of 485 individuals were measured for their DBH, the majority of these stems were from *Acacia aneura* and secondarily *Eucalyptus coolabah* (Table 2). Litter weights showed a great deal of variability within and across alliances (from 5 to 1488 g/m^2). The lowest average weights contained within Alliance 5: Rat's tail Couch – Lovegrass Grasslands and highest within Alliance 8: Poplar Box – Black Box Woodland (Table 3). The highest density of tree hollows per hectare and hollows within logs was found within Alliance 4: Coolibah – Black Box – Yapunyah – Lignum Woodlands (9.5 average with a maximum of 30). The highest average length of logs was within Alliance 1: Mulga Shrublands and the greatest number of overstorey stems within Alliance 8: Poplar Box – Black Box Woodland (Table 3).

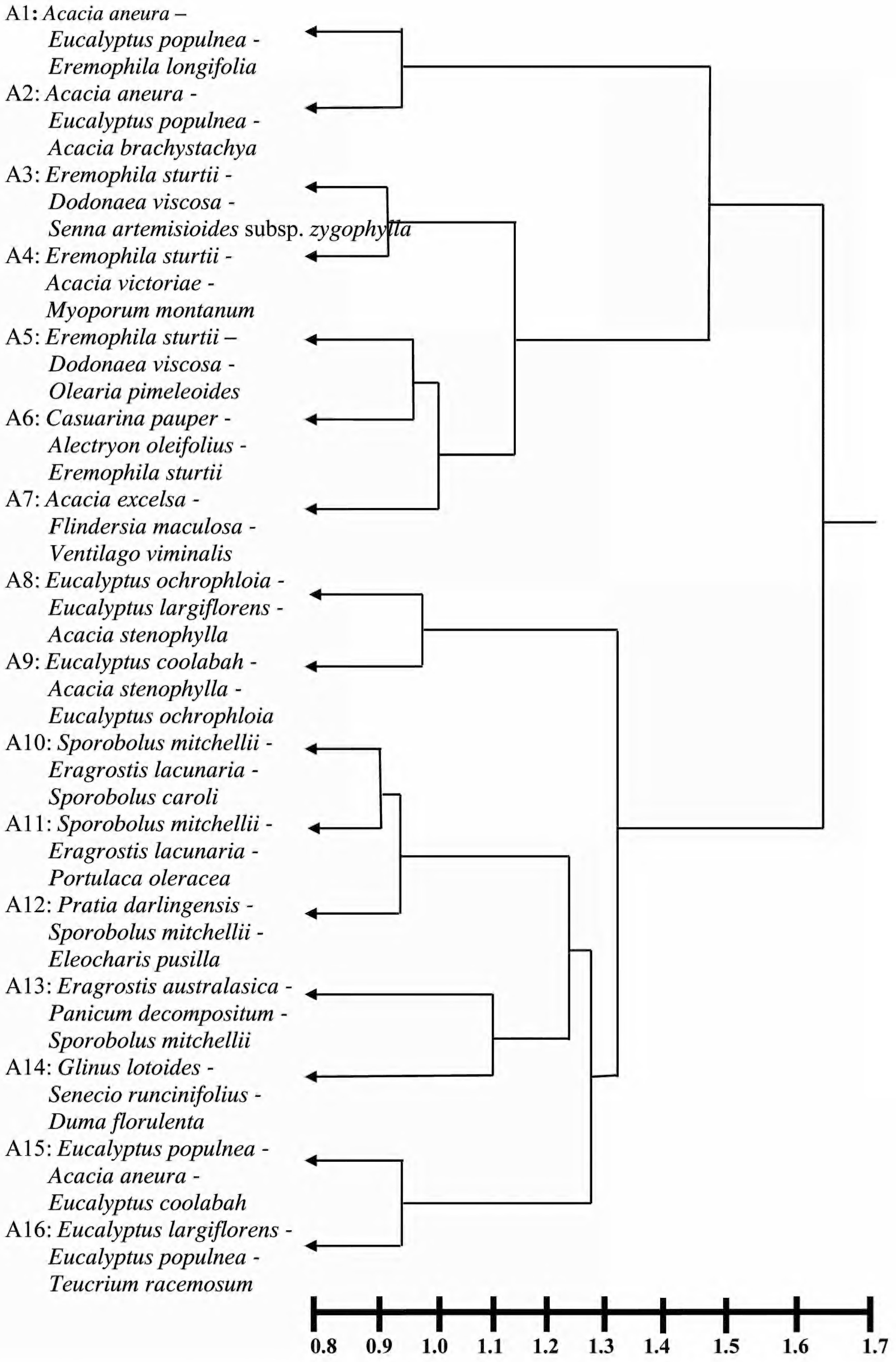
A1: *Acacia aneura – Eucalyptus populnea - Eremophila longifolia*
A2: *Acacia aneura - Eucalyptus populnea - Acacia brachystachya*
A3: *Eremophila sturtii - Dodonaea viscosa - Senna artemisioides* subsp. *zygophylla*
A4: *Eremophila sturtii - Acacia victoriae - Myoporum montanum*
A5: *Eremophila sturtii – Dodonaea viscosa - Olearia pimeleoides*
A6: *Casuarina pauper - Alectryon oleifolius - Eremophila sturtii*
A7: *Acacia excelsa - Flindersia maculosa - Ventilago viminalis*
A8: *Eucalyptus ochrophloia - Eucalyptus largiflorens - Acacia stenophylla*
A9: *Eucalyptus coolabah - Acacia stenophylla - Eucalyptus ochrophloia*
A10: *Sporobolus mitchellii - Eragrostis lacunaria - Sporobolus caroli*
A11: *Sporobolus mitchellii - Eragrostis lacunaria - Portulaca oleracea*
A12: *Pratia darlingensis - Sporobolus mitchellii - Eleocharis pusilla*
A13: *Eragrostis australasica - Panicum decompositum - Sporobolus mitchellii*
A14: *Glinus lotoides - Senecio runcinifolius - Duma florulenta*
A15: *Eucalyptus populnea - Acacia aneura - Eucalyptus coolabah*
A16: *Eucalyptus largiflorens - Eucalyptus populnea - Teucrium racemosum*
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7

Fig. 3. Summary dendrogram with associations defined at a dissociation of *c.* 0.9.

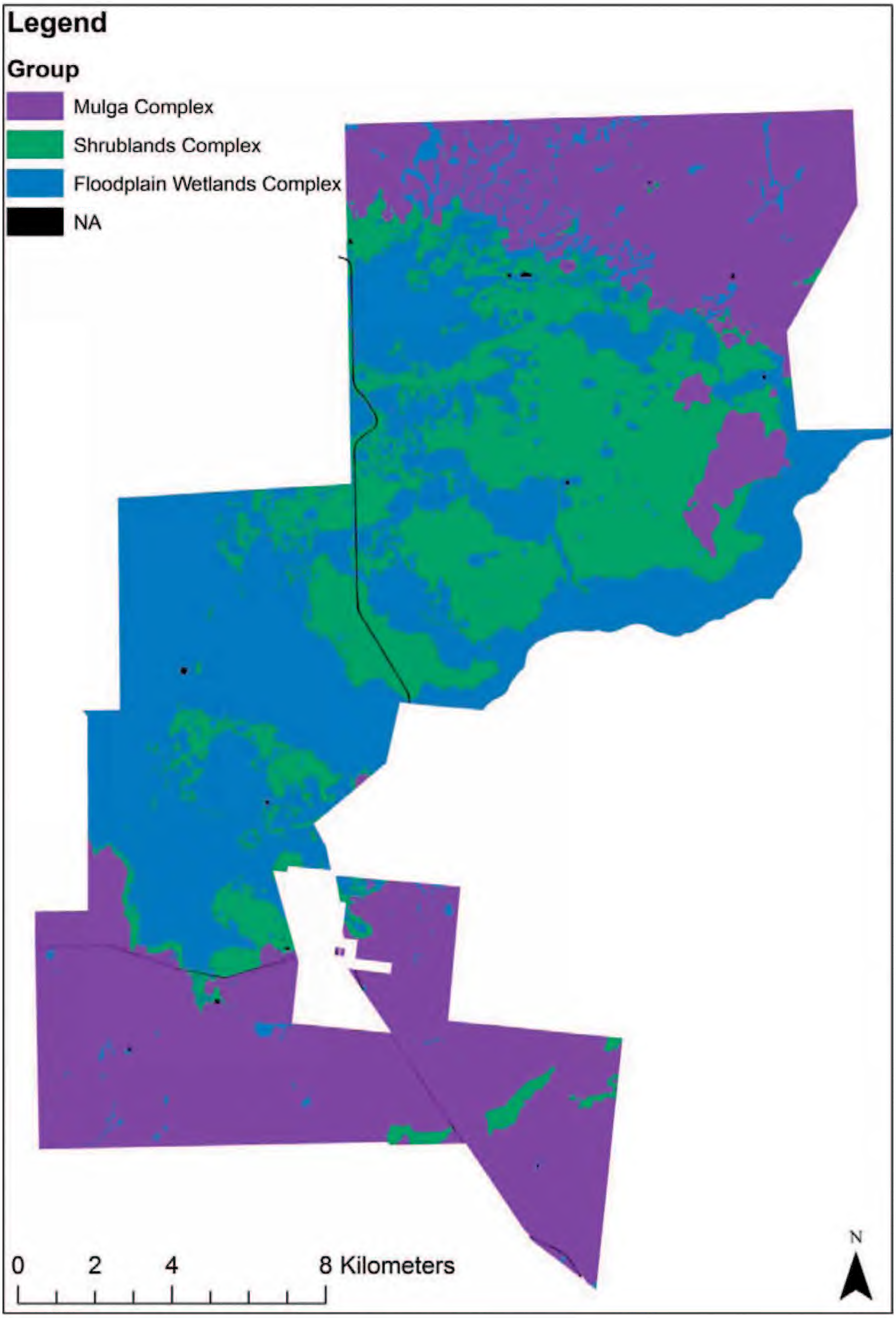

Fig. 4. Mapped distribution of floristic groups within *Naree* and *Yantabulla* stations.

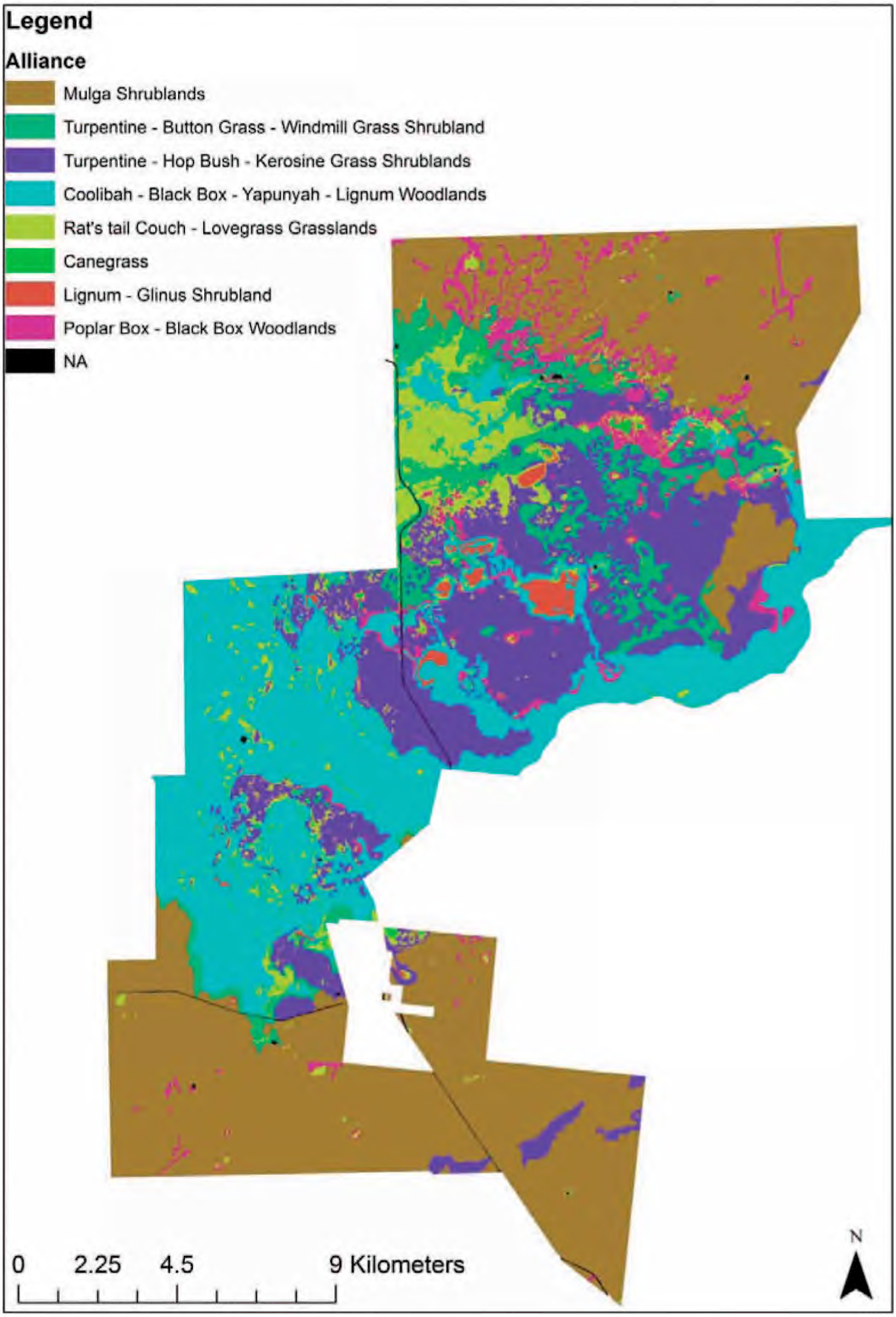
Legend
Alliance
Mulga Shrublands
Turpentine - Button Grass - Windmill Grass Shrubland
Turpentine - Hop Bush - Kerosine Grass Shrublands
Coolibah - Black Box - Yapunyah - Lignum Woodlands
Rat's tail Couch - Lovegrass Grasslands
Canegrass
Lignum - Glinus Shrubland
Poplar Box - Black Box Woodlands
NA
0 2.25 4.5 9 Kilometers
N

Fig. 5. Mapped floristic alliances within *Naree* and *Yantabulla* stations.

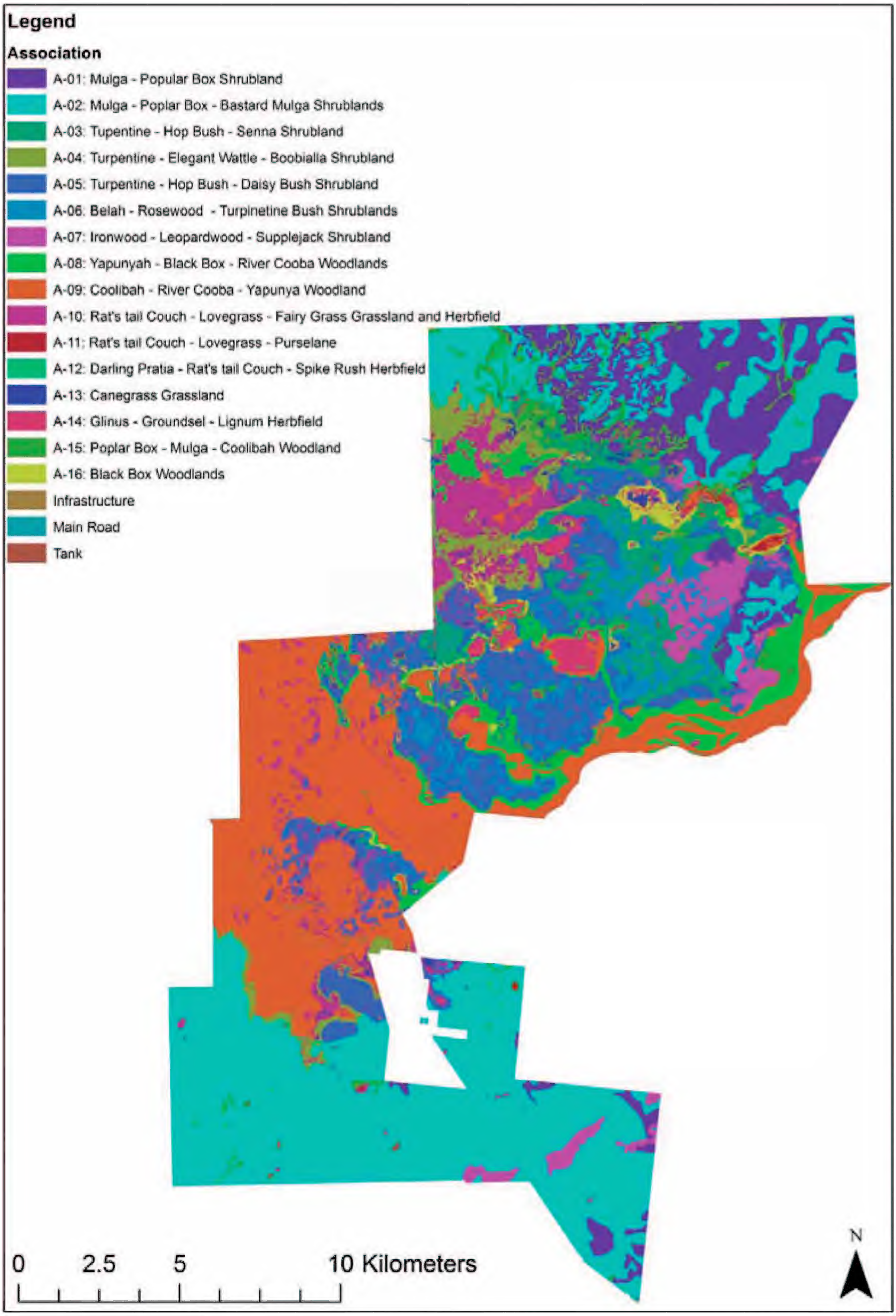
Legend
Association
A-01: Mulga - Popular Box Shrubland
A-02: Mulga - Poplar Box - Bastard Mulga Shrublands
A-03: Tupentine - Hop Bush - Senna Shrubland
A-04: Turpentine - Elegant Wattle - Boobialla Shrubland
A-05: Turpentine - Hop Bush - Daisy Bush Shrubland
A-06: Belah - Rosewood - Turpinetine Bush Shrublands
A-07: Ironwood - Leopardwood - Supplejack Shrubland
A-08: Yapunyah - Black Box - River Cooba Woodlands
A-09: Coolibah - River Cooba - Yapunya Woodland
A-10: Rat's tail Couch - Lovegrass - Fairy Grass Grassland and Herbfield
A-11: Rat's tail Couch - Lovegrass - Purselane
A-12: Darling Pratia - Rat's tail Couch - Spike Rush Herbfield
A-13: Canegrass Grassland
A-14: Glinus - Groundsel - Lignum Herbfield
A-15: Poplar Box - Mulga - Coolibah Woodland
A-16: Black Box Woodlands
Infrastructure
Main Road
Tank
0
2.5
5
10 Kilometers
N

Fig. 6. Mapped floristic associations at *Naree* and *Yantabulla* stations.

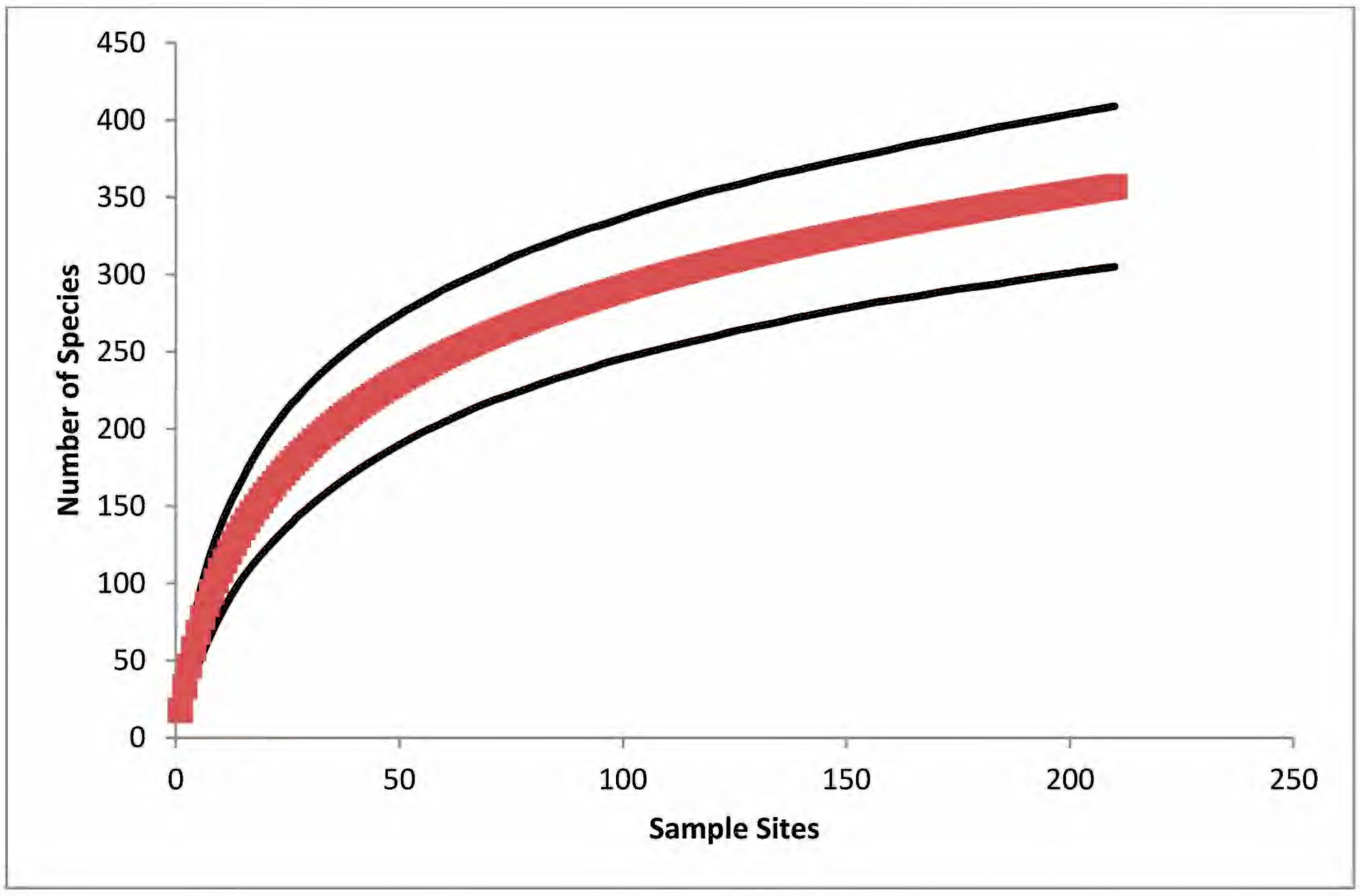

Fig. 7. Coleman rarefaction curves of predicted number of species within *Naree* and *Yantabulla* bounded by 95% confidence limits after 1000 iterations of the dataset. Turnover between sites estimates that the predicted number of species based on differences between full floristic survey sites would be 340 with an upper limit of 410 (95% confidence).

Table 1: Select site attributes of floristic survey plots within hierarchical floristic units.

Type	Full floristic sites	Rapid floristic sites	Total species	Average richness per site (range)	Hectares mapped
Group 1	54	69	180	18 (8-48)	12,450
Alliance 1	54	69	180	18 (8-48)	12,450
Association 1	14	32	132	25 (10-48)	2,908
Association 2	40	37	126	15 (8-28)	9,542
Group 2	46	74	174	16 (7-41)	12,450
Alliance 2	12	33	103	18 (7-41)	2,541
Association 3	6	19	90	30 (24-41)	1,545
Association 4	6	14	27	10 (7-14)	1,071
Alliance 3	34	41	138	15 (8-25)	5,435
Association 5	17	23	93	14 (8-22)	3,143
Association 6	6	8	48	13 (9-20)	1,414
Association 7	11	10	75	17 (11-25)	810
Group 3	103	86	227	15 (1-34)	7,970
Alliance 4	45	37	116	12 (8-21)	7,787
Association 8	22	11	80	13 (8-14)	1,533
Association 9	23	26	92	14 (7-21)	6,248
Alliance 5	33	14	142	17 (7-34)	2,101
Association 10	22	12	113	8 (7-34)	2,005
Association 11	7	1	54	15 (12-25)	57
Association 12	4	1	38	15 (9-21)	39
Alliance 6	2	11	11	6 (1-11)	175
Association 13	2	11	11	6 (1-11)	175
Alliance 7	7	3	32	8 (4-16)	268
Association 14	7	3	32	8 (4-16)	268
Alliance 8	18	21	123	19 (4-19)	1,364
Association 15	13	15	113	22 (6-43)	1,058
Association 16	5	6	113	10 (4-19)	307

Table 2: Diameter measurements in centimetres of the primary stem (>5 cm DBH) of trees within select plots at *Naree* and *Yantabulla* Stations.

Species	Average	Minimum	Maximum	Stems
Acacia aneura	15	5	32	212
Acacia brachystachya	15	13	16	3
Acacia excelsa	29	5	52	14
Acacia stenophylla	12	6	23	25
Alectryon oleifolius	34	18	58	9
Atalaya hemiglauca	6	6	6	1
Corymbia tumescens	16	13	21	10
Eremophila bignoniiflora	10	8	16	8
Eremophila longifolia	8	6	9	3
Eucalyptus coolabah	20	5	72	77
Eucalyptus largiflorens	20	5	49	47
Eucalyptus ochrophloia	28	9	56	8
Eucalyptus populnea	17	5	59	44
Grevillea striata	52	8	80	6
Hakea ivoryi	26	8	43	15
Owenia acidula	53	46	60	2
Ventilago viminalis	70	70	70	1

Table 3: Select habitat attributes of permanently marked habitat plots within floristic alliances; average (range).

Alliance	Number of sites	Litter average weight (g/m²)	% Projected foliage cover	Tree hollows (0.1 ha)	Log length (m/0.1 ha)	Hollows in logs (0.1 ha)	Stems > 5 cm DBH/ha	Shrubs > 1 m height (20 x 20 m)	Shrubs < 1 m height (5 x 5 m)
Alliance 1	16	272 (77-641)	26 (0.2-72)	2.5 (0-9)	75.6 (0-189)	9.0 (0-23)	284 (11-840)	3 (0-8)	20 (8-47)
Alliance 2	5	112 (5-468)	3 (0-18)	0.6 (0-3)	32.0 (0-160)	1.8 (0-9)	4 (0-21)	30 (0-131)	13 (0-65)
Alliance 3	6	162 (41-374)	0	1.7 (0-5)	1.2 (0-4)	0	15 (0-58)	110 (2-377)	7 (0-28)
Alliance 4	8	500 (27-1059)	13 (0-32)	9.5 (0-30)	20.3 (0-88)	10.0 (0-46)	138 (0-320)	44 (2-99)	20 (0-122)
Alliance 5	14	56 (5-142)	6 (0-19)	1.6 (0-14)	11.9 (0-138)	1.8 (0-13)	17 (0-136)	1 (1-8)	2 (0-11)
Alliance 6	2	100 (73-128)	0	0	0	0	0	1	0
Alliance 7	1	239 (239)	0	0	0	0	0	30	0
Alliance 8	3	899 (563-1488)	29 (20-40)	7 (1-18)	23.3 (13-18)	5.3 (3-7)	462 (188-750)	35 (0-102)	5 (0-14)

Vegetation assemblages

Species are listed in decreasing order of fidelity (cover x frequency).

Group 1: Mulga Complex

Alliance 1: Mulga Shrublands

Common Overstorey: *Acacia aneura, Eucalyptus populnea, Acacia brachystachya, Hakea ivoryi, Corymbia tumescens.*

Common Mid-storey: *Eremophila longifolia, Eremophila gilesii, Senna artemisioides* subsp. *zygophylla, Senna artemisioides* subsp. *filifolia, Eremophila sturtii, Dodonaea viscosa.*

Common Understorey: *Eragrostis eriopoda, Digitaria brownii, Aristida jerichoensis, Monachather paradoxus, Aristida holathera, Fimbristylis dichotoma, Solanum cleistogamum, Cheilanthes sieberi, Panicum effusum, Eragrostis laniflora, Thyridolepis mitchelliana.*

Association 1: *Acacia aneura* (Mulga) – *Eucalyptus populnea* (Poplar Box) Woodland and Shrubland (Fig. 8).

Environmental relationships: found primarily on red soils on higher topographic positions such as ridges and low plateau areas. Soils can be hard red clay pans and gibber/red clay/red sand landscapes.

Structure: generally a tall shrubland but occasionally a shrubland to low open woodland or layered woodland.

- Tall shrub or low tree layer: (3-) 5-7 (-12) m tall. (5-) 25-35 (-70)% cover.
- Shrub layer: 1-2 (-7) m tall. 10-20 (-60)% cover. Rarely absent.
- Low shrub layer very rarely present.
- Understorey layer: 0.1-0.5 m tall. (10-) 30-35 (-70)% cover.

Trees: *Acacia aneura, Eucalyptus populnea, Hakea ivoryi, Corymbia tumescens.*

Shrubs: *Eremophila longifolia, Solanum cleistogamum, Senna artemisioides* subsp. *filifolia, Solanum parvifolium, Thryptomene hexandra, Senna artemisioides* subsp. x *coriacea*, *Maireana brevifolia, Solanum cinereum, Senna artemisioides* subsp. *zygophylla*, *Sclerolaena diacantha, Hakea eryeana, Eremophila gilesii*.

Climbers & trailers: *Convolvulus clementii, Glycine canescens, Convolvulus remotus.*

Ground cover: *Fimbristylis dichotoma, Cheilanthes sieberi, Panicum effusum, Digitaria brownii, Calotis inermis, Calotis hispidula, Tripogon loliiformis, Aristida jerichoensis, Aristida holathera, Enneapogon avenaceus, Pimelea trichostachya, Nicotiana simulans, Monachather paradoxus, Erodium crinitum, Centipeda thespidioides, Vittadinia cuneata, Goodenia glabra, Chenopodium melanocarpum, Digitaria divaricatissima, Dactyloctenium radulans, Eragrostis leptocarpa, Digitaria ammophila, Chamaesyce drummondii, Calandrinia eremaea, Wahlenbergia tumidifructa, Thyridolepis mitchelliana, Ptilotus gaudichaudii, Omphalolappula concava, Eragrostis setifolia, Enneapogon nigricans, Calotis lappulacea, Velleia arguta, Trachymene ochracea, Sida trichopoda, Sida fibulifera, Ptilotus polystachyus, Portulaca oleracea, Paspalidium constrictum, Oxalis perennans, Goodenia cycloptera, Dysphania rhadinostachya, Digitaria hystrichoides, Aristida leptopoda, Triraphis mollis, Swainsona affinis, Solanum esuriale, Solanum ellipticum, Solanum coactiliferum, Sclerolaena convexula, Ptilotus leucocoma, Plantago turrifera, Hibiscus sturtii, Eragrostis lacunaria, Enneapogon intermedius, Chloris truncata, Centipeda crateriformis, Tragus australianus, Trachymene glaucifolia, Themeda triandra, Stuartina muelleri, Streptoglossa liatroides, Pycnosorus thompsonianus, Perotus rara, Panicum simile, Marsilea drummondii, Evolvulus alsinoides, Eragrostis parviflora, Eragrostis leptostachya, Eragrostis eriopoda, Enteropogon acicularis, Einadia trigonos, Dianella porracea, Crassula sieberiana, Aristida latifolia, Aristida contorta, Aristida calycina, Abutilon oxycarpum*.

Introduced taxa: *Malvastrum americanum, Cenchrus ciliaris, Ammi majus.*

Association 2: *Acacia aneura* (Mulga) - *Eucalyptus populnea* (Poplar Box) – *Acacia brachystachya* (Bastard or Umbrella Mulga) Woodland and Shrubland (Fig. 9).

Environmental relationships: found primarily of red soils on higher topographic positions such as ridges and low plateau areas. Soils can be hard red clay pans and gibber/red clay/red sand landscapes.

Structure: usually a tall shrubland but often a shrubland and low open woodland or layered woodland.

- Tall shrub or low tree-layer: 4-7 (-14) m tall. (2-) 20-30 (-80)% cover.
- Shrub layer: 1.5-2.5 (-9.5) m tall. (2-) 15-25 (-50)% cover. Rarely absent.
- Low shrub-layer rarely present.
- Understorey layer: 0.1-1 m tall. (5-) 30-35 (-70)% cover.

Trees: *Acacia aneura, Eucalyptus populnea, Acacia brachystachya, Hakea ivoryi, Corymbia tumescens, Grevillea striata, Callitris glaucophylla, Acacia ramulosa, Eucalyptus melanophloia, Acacia excelsa*.

Shrubs: *Solanum cleistogamum, Eremophila longifolia, Eremophila gilesii, Senna artemisioides* subsp. *zygophylla, Maireana villosa, Dodonaea viscosa, Eremophila sturtii, Senna artemisioides* subsp. *filifolia, Sclerolaena convexula, Thryptomene hexandra, Sclerolaena diacantha, Sclerolaena birchii, Solanum ferocissimum, Solanum ellipticum, Eremophila bowmanii, Solanum parvifolium, Eremophila latrobei.*

Climbers & trailers: *Convulvus remotus.*

Ground cover: *Eragrostis eriopoda, Aristida jerichoensis, Digitaria brownii, Monachather paradoxus, Aristida holathera, Eragrostis parviflora, Panicum effusum, Fimbristylis dichotoma, Hibiscus sturtii, Eriachne helmsii, Cheilanthes sieberi, Thyridolepis mitchelliana, Digitaria divaricatissima, Calotis cuneifolia, Enneapogon avenaceus, Triraphis mollis, Dactyloctenium radulans, Tripogon loliiformis, Ptilotus gaudichaudii, Omphalolappula concava, Sida trichopoda, Perotus rara, Panicum simile, Tragus australianus, Dysphania rhadinostachya, Calotis lappulacea, Thyridolepis xerophila, Pimelea trichostachya, Sporobolus actinocladus, Sida filiformis, Paspalidium constrictum, Goodenia cycloptera, Chamaesyce drummondii, Centipeda thespidioides, Amphipogon caricinus, Velleia arguta, Leptorhynchos baileyi, Enneapogon cylindricus, Aristida contorta, Sida platycalyx, Sida cunninghamii, Ptilotus polystachyus, Ptilotus leucocoma, Mollugo cerviana, Gypsophyla tubulosa, Eriachne mucronata, Eragrostis lacunaria, Eragrostis kennedyae, Enteropogon acicularis, Cymbopogon ambiguus, Boerhavia coccinea, Aristida nitidula, Aristida blakei.*

Introduced taxa: *Sisymbrium erysimoides, Ammi majus, Eragrostis cilianensis.*

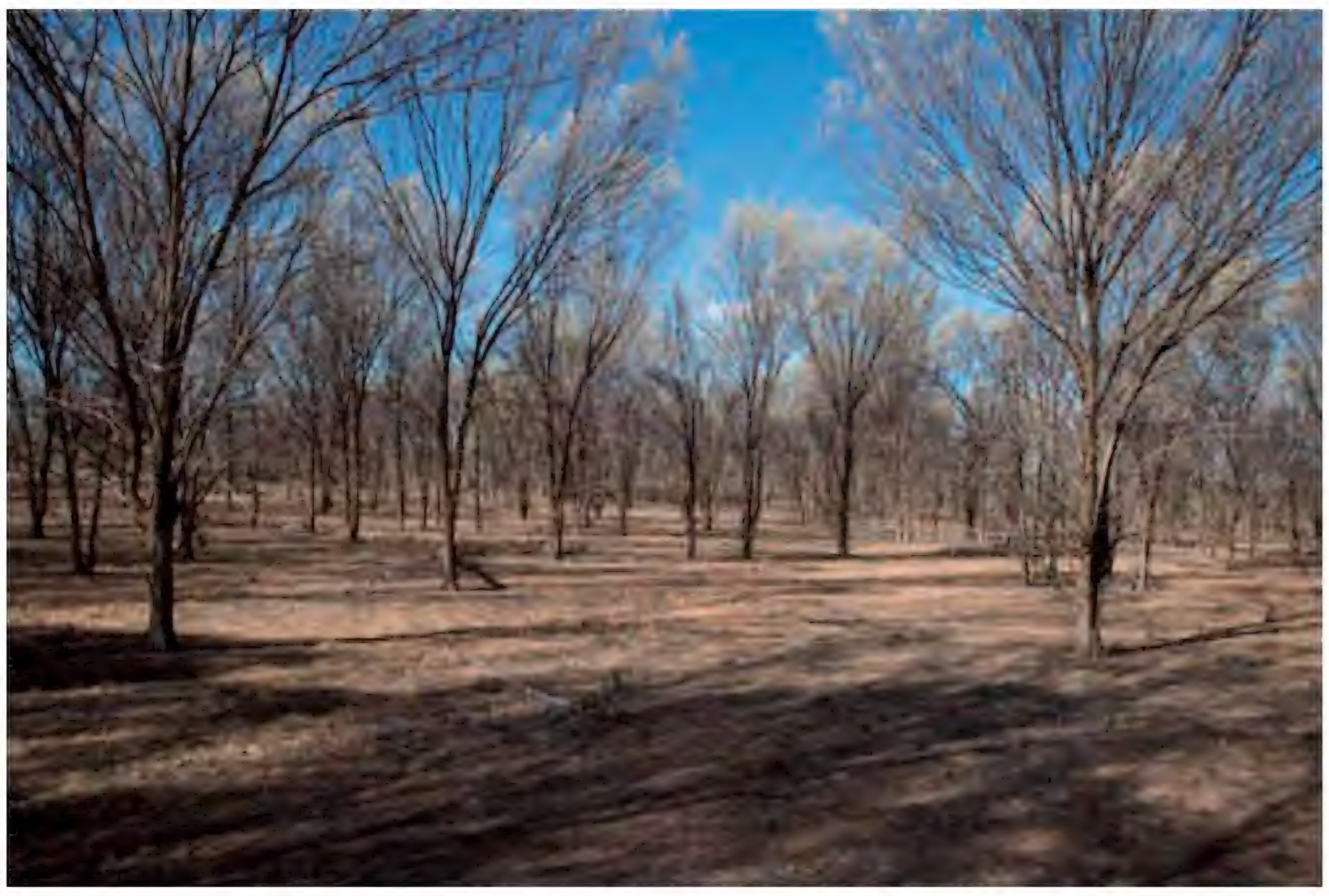

Fig. 8. Group 1: Mulga Complex; Alliance 1: Mulga Shrublands; Association 1: *Acacia aneura – Eucalyptus populnea* Woodland and Shrubland.

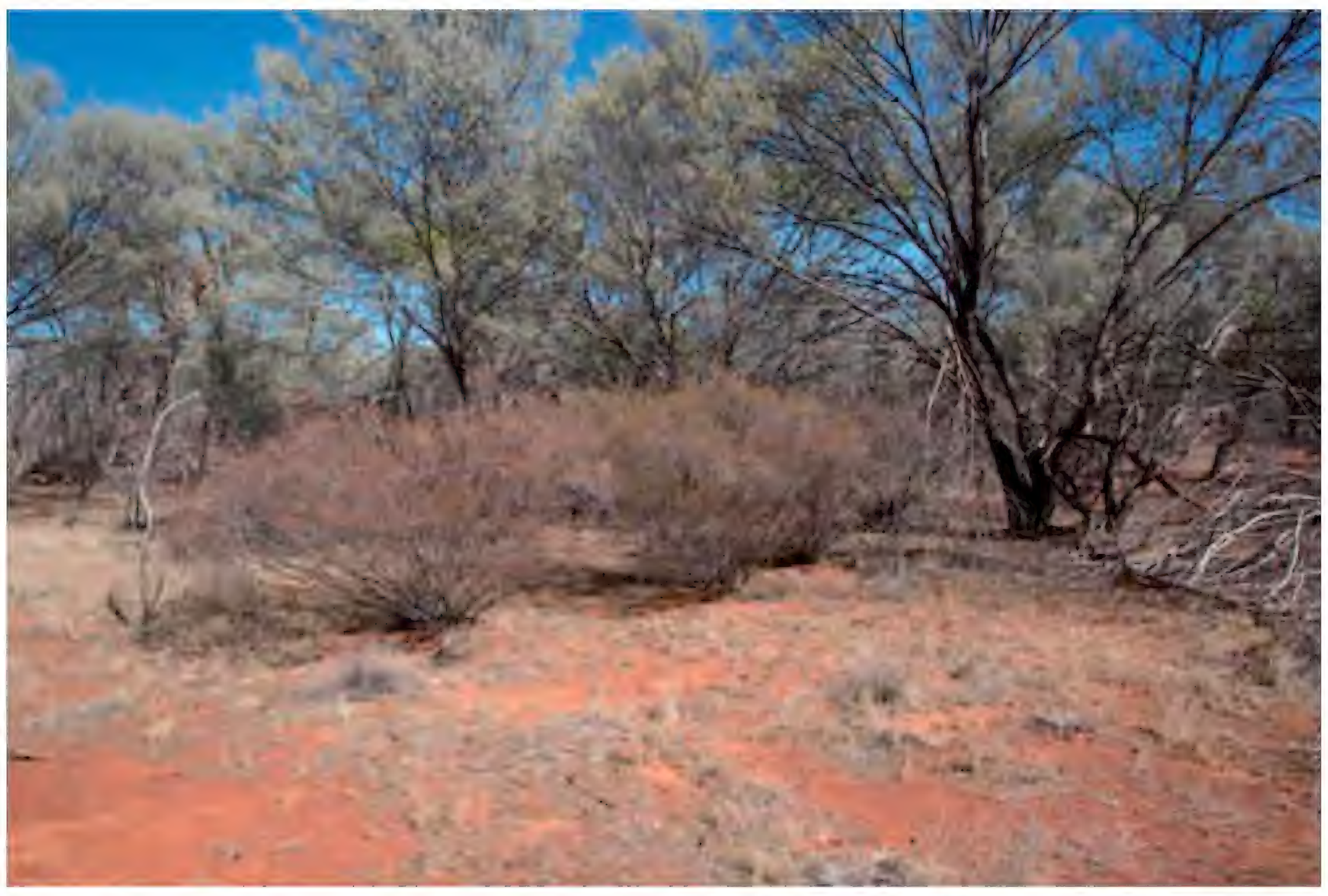

Fig. 9. Group 1: Mulga Complex; Alliance 1: Mulga Shrublands; Association 1: *Acacia aneura – Eucalyptus populnea – Acacia brachystachya* Woodland and Shrubland.

Group 2: Shrubland Complex

Common Overstorey: *Acacia excelsa, Alectryon oleifolius, Casuarina pauper, Ventilago viminalis, Flindersia maculosa*.

Common Mid-storey: *Eremophila sturtii, Dodonaea viscosa, Senna artemisioides* subsp. *zygophylla, Olearia pimeleoides, Eremophila deserti, Acacia victoriae*.

Common Understorey: *Aristida holathera, Enteropogon acicularis, Enneapogon avenaceus, Eragrostis eriopoda, Dissocarpus paradoxus, Sclerolaena diacantha, Enchylaena tomentosa, Dactyloctenium radulans, Eragrostis laniflora*.

Within this complex, structure varies considerably from open to dense shrublands or open shrubby woodlands. The assemblages within this Group are generally distinguished by their often dense cover of encroaching native woody species (locally known as 'Woody Weeds'), particularly of *Eremophila* spp., *Dodonaea* spp. and *Senna* spp.. In some instances, the remnants of original tropical woodlands remain but it is also likely that dense shrublands of these types were also present in some form prior to agricultural intervention.

Alliance 2: Turpentine – Button Grass – Windmill Grass Shrubland

Common Overstorey: *Acacia excelsa, Casuarina pauper, Alectryon oleifolius*. (Overstorey rarely present).

Common Mid-storey: *Eremophila sturtii, Dodonaea viscosa, Senna artemisioides* subsp. *zygophylla, Olearia pimeleoides, Dodonaea viscosa, Myoporum montanum, Acacia victoriae.*

Common Understorey: *Dactyloctenium radulans, Enteropogon acicularis, Portulaca oleracea, Abutilon otocarpum, Chenopodium cristatum, Eragrostis setifolia, Enneapogon avenaceus, Enchylaena tomentosa, Tragus australianus, Sclerolaena diacantha, Aristida jerichoensis*.

Generally, found on lower physiographic positions often associated with wetland, playa-lake and swamp margins. Soils can be sandy to clayey red brown earths but often with higher clay content. This sub-assemblage also occurs in areas of wind and water erosion where alternating patches of red dune sand occur with flats of calcium carbonate near the surface.

Association 3: *Eremophila sturtii* (Turpentine Bush) – *Dodonaea viscosa* (Hop Bush) Shrubland (Fig. 10).

Environmental relationships: found associated with minor dunes around playa lakes and wetland systems.

Structure: a low shrubby woodland or shrubland to open grassy shrubland.

- Tall shrub-layer: (1-) 3-6 m (-8) tall. (5-) 20-30 (-70) % cover.
- Shrub layer: 1-3 (-5) m tall. (15-) 30-40 (-70)% cover.
- Low shrub layer rarely present.
- Understorey layer: 0.1-0.5 (-0.8) m tall. (10-) 20-30 (-60)% cover.

Trees: *Acacia excelsa, Casuarina pauper, Alectryon oleifolius.*

Shrubs: *Eremophila sturtii, Dodonaea viscosa, Senna artemisioides* subsp. *zygophylla, Olearia pimeleoides, Dissocarpus paradoxus, Solanum coactiliferum, Sclerolaena lanicuspis, Sclerolaena bicornis, Senna artemisioides* subsp. x *sturtii, Sclerolaena muricata, Sclerolaena convexula, Myoporum montanum, Chenopodium desertorum, Atriplex limbata, Senna artemisioides* subsp. *filifolia, Pimelea microcephala, Maireana triptera, Maireana brevifolia.*

Climbers & trailers: *Jasminum lineare.*

Ground cover: *Enteropogon acicularis, Dactyloctenium radulans, Portulaca oleracea, Chenopodium cristatum, Abutilon otocarpum, Eragrostis setifolia, Enneapogon avenaceus, Enchylaena tomentosa, Tragus australianus, Aristida jerichoensis, Aristida holathera, Trianthema triquetra, Digitaria brownii, Wahlenbergia tumidifructa, Triraphis mollis, Sida filiformis, Sida fibulifera, Eragrostis microcarpa, Calandrinia eremaea, Perotus rara, Paspalidium constrictum, Monachather paradoxus, Eragrostis parviflora, Cheilanthes sieberi, Chamaesyce drummondii, Boerhavia coccinea, Zygophyllum iodocarpum, Sida trichopoda, Ptilotus polystachyus, Pimelea trichostachya, Omphalolappula concava, Hibiscus sturtii, Goodenia glabra, Brachyscome ciliaris.*

Introduced taxa: *Eragrostis cilianensis, Tribulus terrestris, Cucumis myriocarpus, Cenchrus ciliaris*.

Association 4: *Eremophila sturtii* (Turpentine Bush) – *Acacia victoriae* (Elegant Wattle) Shrubland (Fig. 11).

Environmental relationships: strongly associated with lower dunal positions surrounding playa lakes and wetland areas. Usually with less sandy material and higher clay and calcium carbonate content within the soil profile than Alliance 3.

Structure: shrubland and often a very open shrubland to herbaceous or grassy shrubland, sometimes with very little above ground biomass at all.

- Shrub-layer: (1-) 2-5 m tall. 5-25 (-80)% cover.
- Understorey layer: 0.1-0.5 (-1) m tall. (1-) 20-30 (-70)% cover.

Trees: none apparent.

Shrubs: *Eremophila sturtii, Sclerolaena birchii, Atriplex pseudocampanulata, Atriplex eardleyae, Acacia victoriae, Myoporum montanum, Maireana villosa, Eremophila deserti, Dodonaea viscosa, Atriplex stipitata.*

Climbers & trailers: none apparent.

Ground cover: *Dactyloctenium radulans, Eragrostis dielsii, Eleocharis pusilla, Cyperus difformis, Cynodon dactylon, Echinochloa turneriana, Marsilea costulifera, Fimbristylis dichotoma, Abutilon otocarpum, Sporobolus mitchellii, Sida intricate, Sida goniocarpa, Eragrostis parvifolia, Enteropogon acicularis, Einadia nutans.*

Introduced taxa: *Eragrostis cilianensis.*

Alliance 3: Turpentine – Hop Bush – Kerosene Grass Shrubland

Common Overstorey: *Acacia excelsa, Alectryon oleifolius, Casuarina pauper, Ventilago viminalis, Flindersia maculosa, Acacia aneura.*

Common Mid-storey: *Eremophila sturtii, Dodonaea viscosa, Eremophila deserti, Olearia pimeleoides, Senna artemisioides* subsp. *zygophylla, Acacia victoriae, Acacia tetragonophylla, Eremophila glabra.*

Common Understorey: *Aristida holathera, Enteropogon acicularis, Eragrostis eriopoda, Enneapogon avenaceus, Dissocarpus paradoxus, Eragrostis laniflora, Sclerolaena convexula, Sclerolaena diacantha, Monachather paradoxus.*

Layered shrublands found on sandier soils on higher physiographic positions than the Alliance 2. Though often includes areas of internal drainage where clays are deposited above sandier soils.

Association 5: *Eremophila sturtii* (Turpentine Bush) – *Dodonaea viscosa* (Hop Bush) Shrubland (Fig. 12).

Environmental relationships: similar to Community 2 but generally on higher physiographic positions.

Structure: usually a shrubland to open shrubland.

- Tall shrub layer: (2-) 4-6.5 (-12) m tall. (5-) 15-25 (-70)% cover.
- Shrub layer: 1-3 (-5) m tall. (5-) 30-40 (-50)% cover. Rarely absent.
- Low shrub layer rare.
- Ground layer: 0.1-0.4 m (1) tall. (2) 15-20 (50)% cover.

Trees: *Alectryon oleifolius, Atalaya hemiglauca, Ventilago viminalis, Eucalyptus coolabah, Casuarina pauper, Acacia aneura.*

Shrubs: *Eremophila sturtii, Dodonaea viscosa, Olearia pimeleoides, Dissocarpus paradoxus, Eremophila deserti, Acacia victoriae, Acacia tetragonophylla, Sclerolaena diacantha, Sclerolaena decurrens, Sclerolaena convexula, Senna artemisioides* subsp. *zygophylla, Sclerolaena birchii, Chenopodium desertorum, Atriplex turbinata, Sclerolaena tricuspis, Sclerolaena lanicuspis, Myoporum montanum, Eremophila mitchellii, Eremophila longifolia, Enchylaena tomentosa, Atriplex eardleyae, Salsola australis, Pimelea microcephala, Maireana villosa, Hakea tephrosperma, Hakea leucoptera, Eremophila glabra, Atriplex nessorhina.*

Climbers & trailers: none apparent.

Ground cover: *Aristida holathera, Enteropogon acicularis, Enneapogon avenaceus, Eragrostis laniflora, Eragrostis parviflora, Eragrostis eriopoda, Fimbristylis dichotoma, Eragrostis lacunaria, Tripogon loliiformis, Sida trichopoda, Sida filiformis, Cymbopogon ambiguus, Triraphis mollis, Panicum simile, Evolvulus alsinoides, Eragrostis basedowii, Enneapogon cylindricus, Digitaria brownii, Vittadinia dissecta, Trianthema triquetra, Solanum esuriale, Sida ammophila, Einadia nutans, Digitaria hystrichoides, Dactyloctenium radulans.*

Introduced taxa: *Eragrostis cilianensis, Cenchrus ciliaris.*

Association 6: *Casuarina pauper* (Black Oak) – *Alectryon oleifolius* (Rosewood) Shrubland (Fig. 13).

Environmental relationships: found within internal drainage locations on red and red brown earths and dunal areas.

Structure: generally an open layered woodland to layered shrubland. The herbaceous understorey is generally very sparse within *Casuarina pauper* dominated areas.

- Tall shrub layer: (3-) 6-10 (-15) m tall. (10-) 20-30 (-50)% cover.
- Shrub layer: 1-3 m tall. (10-) 30-35 (-70)% cover.
- Understorey layer: 0.1-0.4 m tall. (5-) 10-15 (-30)% cover.

Trees: *Casuarina pauper, Alectryon oleifolius, Eucalyptus populnea, Acacia excelsa, Flindersia maculosa, Acacia aneura.*

Shrubs: *Eremophila sturtii, Dodonaea viscosa, Dissocarpus paradoxus, Sclerolaena diacantha, Salsola australis, Eremophila deserti, Sclerolaena tricuspis, Eremophila mitchellii, Enchylaena tomentosa, Atriplex stipitata, Pimelea microcephala, Myoporum montanum, Eremophila glabra, Chenopodium desertorum, Atriplex limbata, Senna artemisioides* subsp. *zygophylla, Sclerolaena birchii, Santalum acuminatum, Olearia pimeleoides, Capparis mitchellii.*

Climbers & trailers: none apparent.

Ground cover: *Enteropogon acicularis, Paspalidium constrictum, Eragrostis lacunaria, Boerhavia coccinea, Sida filiformis, Chenopodium cristatum, Abutilon otocarpum, Solanum cleistogamum, Sida cunninghamii, Eragrostis parviflora, Enneapogon avenaceus, Einadia nutans, Einadia hastata, Chenopodium melanocarpum, Centipeda* *thespidioides, Atriplex eardleyae, Aristida jerichoensis, Aristida holathera.*

Introduced taxa: *Eragrostis cilianensis, Lycium ferocissimum, Cenchrus ciliaris.*

Association 7: *Acacia excelsa* (Ironwood) – *Flindersia maculosa* (Leopardwood) – *Ventilago viminalis* (Supplejack) Shrubland (Fig. 14).

Environmental relationships: commonly found within internal drainage or sub-soil water accumulation areas on deeper sands and larger dunes.

Structure: generally a layered low open woodland or tall open shrubland.

- Tall shrub layer: (4-) 5-9 (-12) m tall. (5-) 10-15 (-30)% cover.
- Shrub layer: 1-3 (-4) m tall. (5-) 35-40 (-65)% cover. Rarely absent.
- Low shrub layer rarely present.
- Understorey layer: 0.1-0.5 (-1) m tall. (10-) 25-30 (-65)% cover.

Trees: *Acacia excelsa, Flindersia maculosa, Ventilago viminalis, Callitris glaucophylla, Acacia aneura, Grevillea striata, Corymbia tumescens, Acacia brachystachya, Hakea ivoryi.*

Shrubs: *Eremophila sturtii, Senna artemisioides* subsp. *zygophylla, Sclerolaena convexula, Eremophila deserti, Enchylaena tomentosa, Dodonaea viscosa, Senna artemisioides* subsp. *filifolia, Olearia pimeleoides, Chenopodium desertorum, Sclerolaena muricata, Eremophila glabra, Dodonaea boroniifolia, Eremophila longifolia, Dissocarpus paradoxus, Alstonia constricta.*

Climbers & trailers: none apparent.

Ground cover: *Aristida holathera, Eragrostis eriopoda, Monachather paradoxus, Aristida jerichoensis, Eragrostis laniflora, Enteropogon acicularis, Enneapogon avenaceus, Abutilon otocarpum, Solanum cleistogamum, Ptilotus leucocoma, Evolvulus alsinoides, Eriachne aristidea, Chamaesyce drummondii, Boerhavia coccinea, Tragus australianus, Sida filiformis, Ptilotus polystachyus, Hibiscus sturtii, Eragrostis parviflora, Digitaria brownii, Calotis lappulacea, Calocephalus sonderi, Velleia arguta, Thyridolepis mitchelliana, Sida platycalyx, Panicum simile, Eragrostis kennedyae, Digitaria divaricatissima, Cheilanthes sieberi, Calotis cuneifolia, Brachyscome ciliaris, Aristida contorta, Solanum ferocissimum, Solanum esuriale, Sida trichopoda, Ptilotus sessilifolius, Pimelea trichostachya, Perotus rara, Panicum effusum, Gnephosis arachnoidea, Fimbristylis dichotoma, Enneapogon polyphyllus, Calotis erinacea, Bulbine alata, Aristida leptopoda.*

Introduced taxa: *Cenchrus ciliaris.*

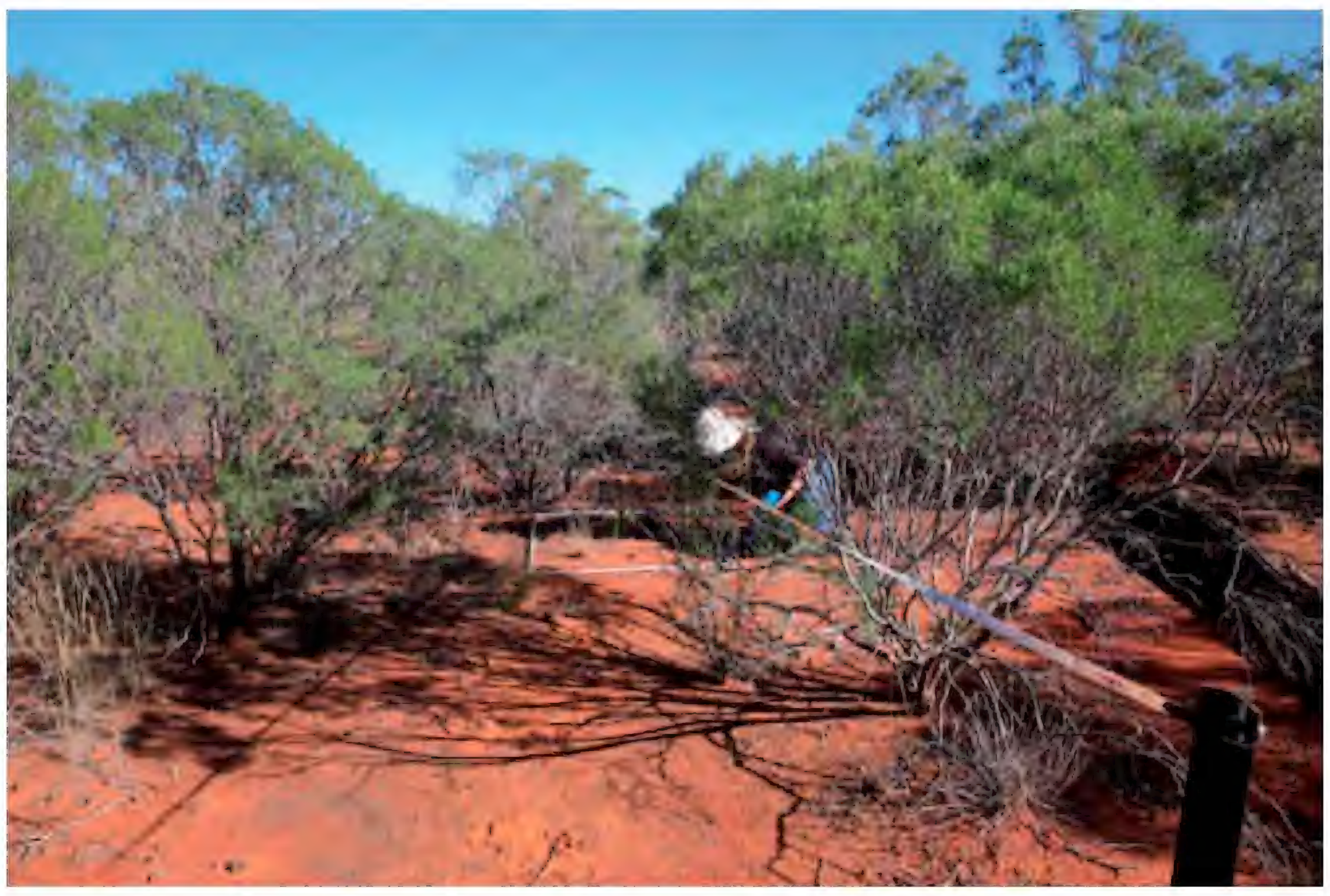

Fig. 10. Group 2: Shrubland Complex; Alliance 2: Turpentine – Button Grass – Windmill Grass Shrubland; Association 3: *Eremophila sturtii – Dodonaea viscosa* Shrubland.

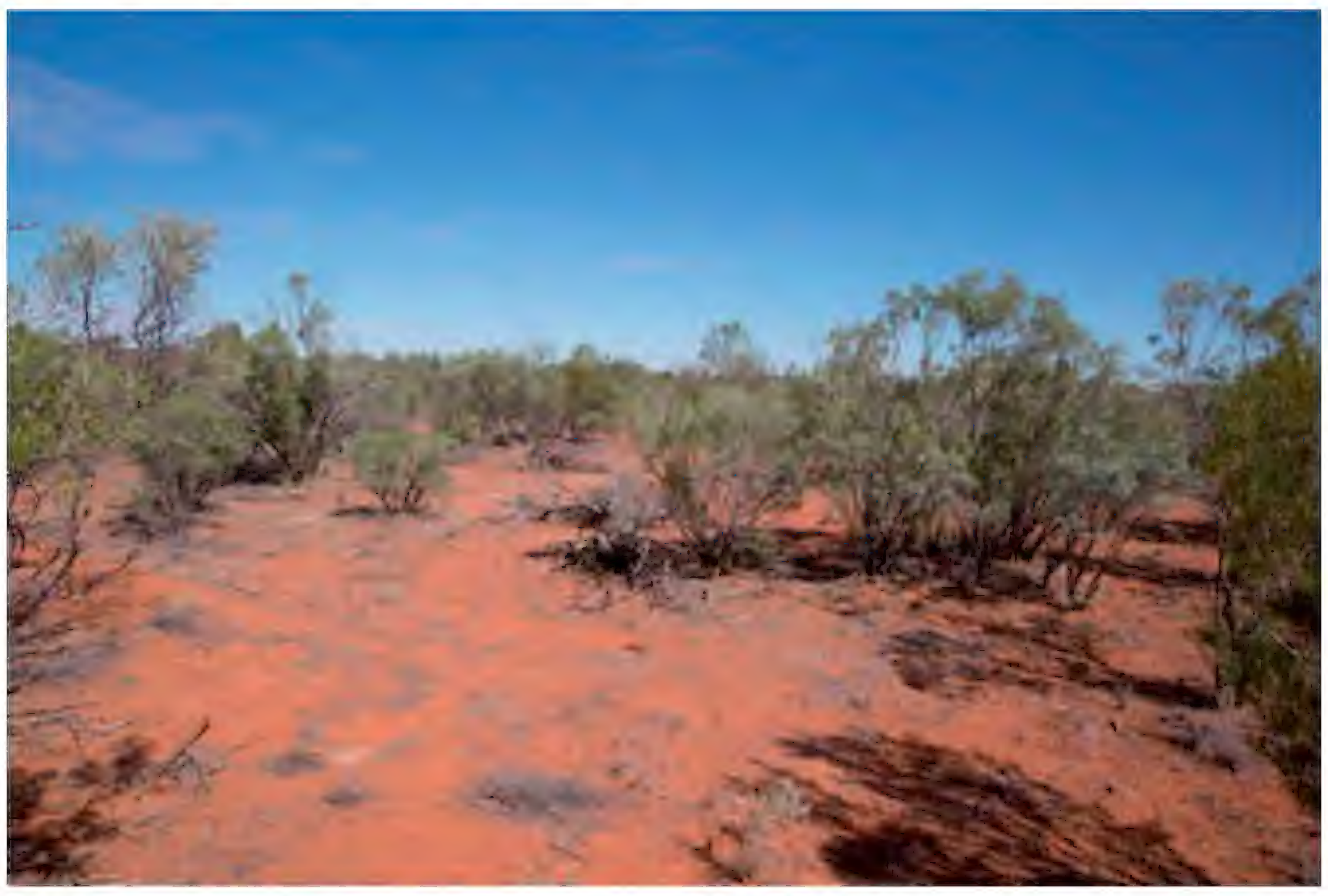

Fig. 11. Group 2: Shrubland Complex; Alliance 2: Turpentine – Button Grass – Windmill Grass Shrubland; Association 4: *Eremophila sturtii – Acacia victoriae* Shrubland.

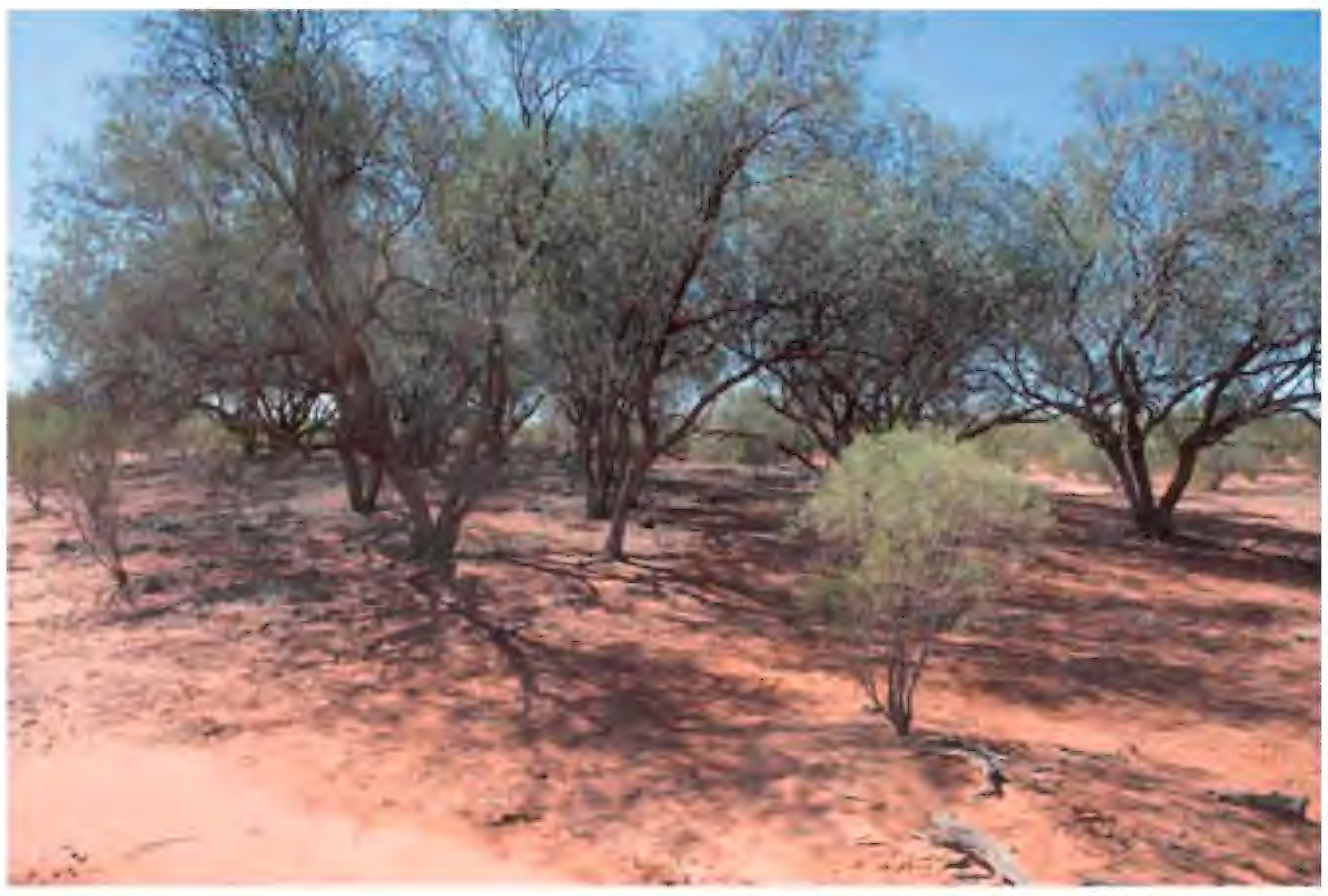

Fig. 12. Group 2: Shrubland Complex; Alliance 3: Turpentine – Hop Bush – Kerosine Grass Shrubland; Association 5: *Eremophila sturtii – Dodonaea viscosa* Shrubland.

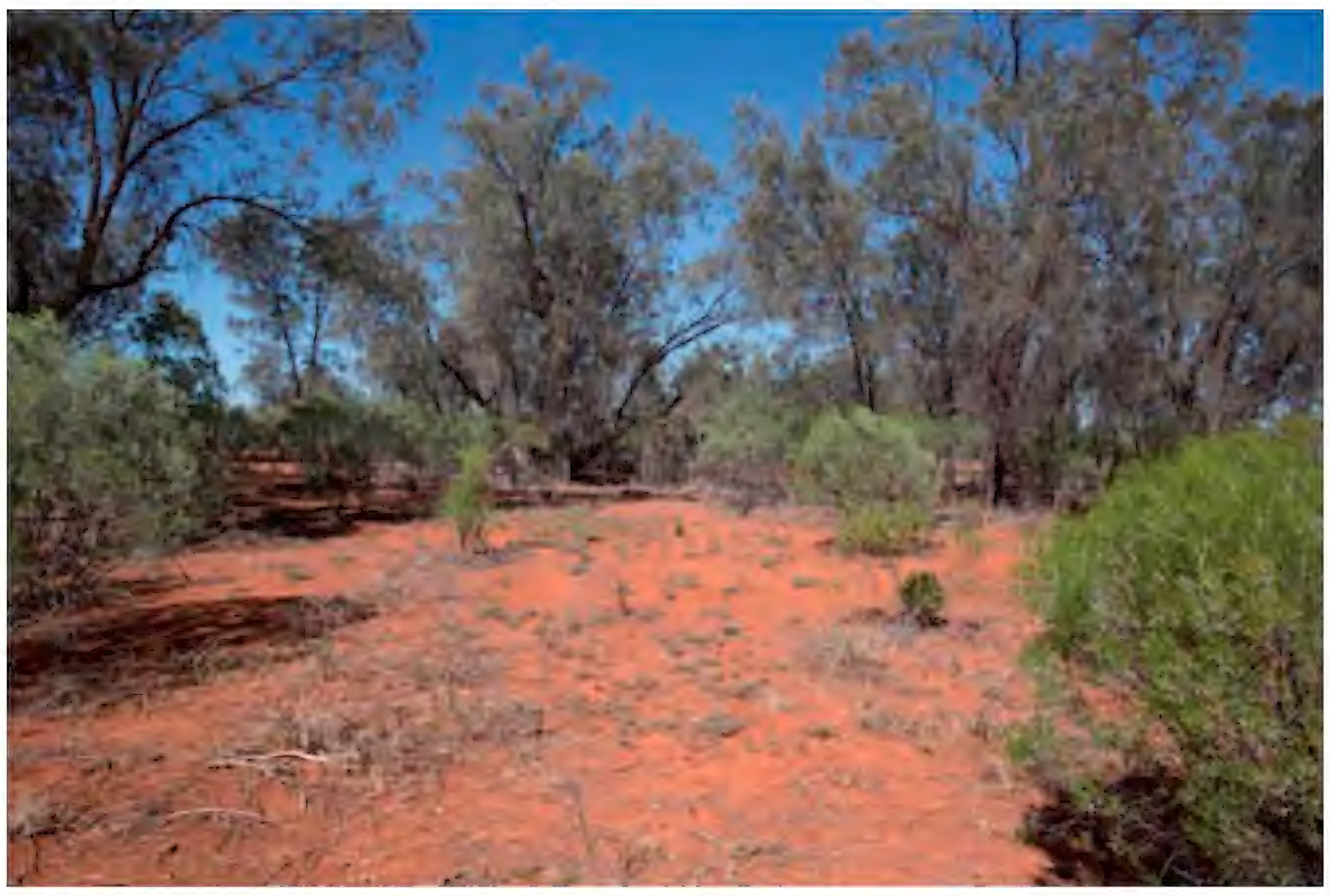

Fig. 13. Group 2: Shrubland Complex; Alliance 3: Turpentine – Hop Bush – Kerosine Grass Shrubland; Association 6: *Casuarina pauper – Alectryon oleifolius* Shrubland.

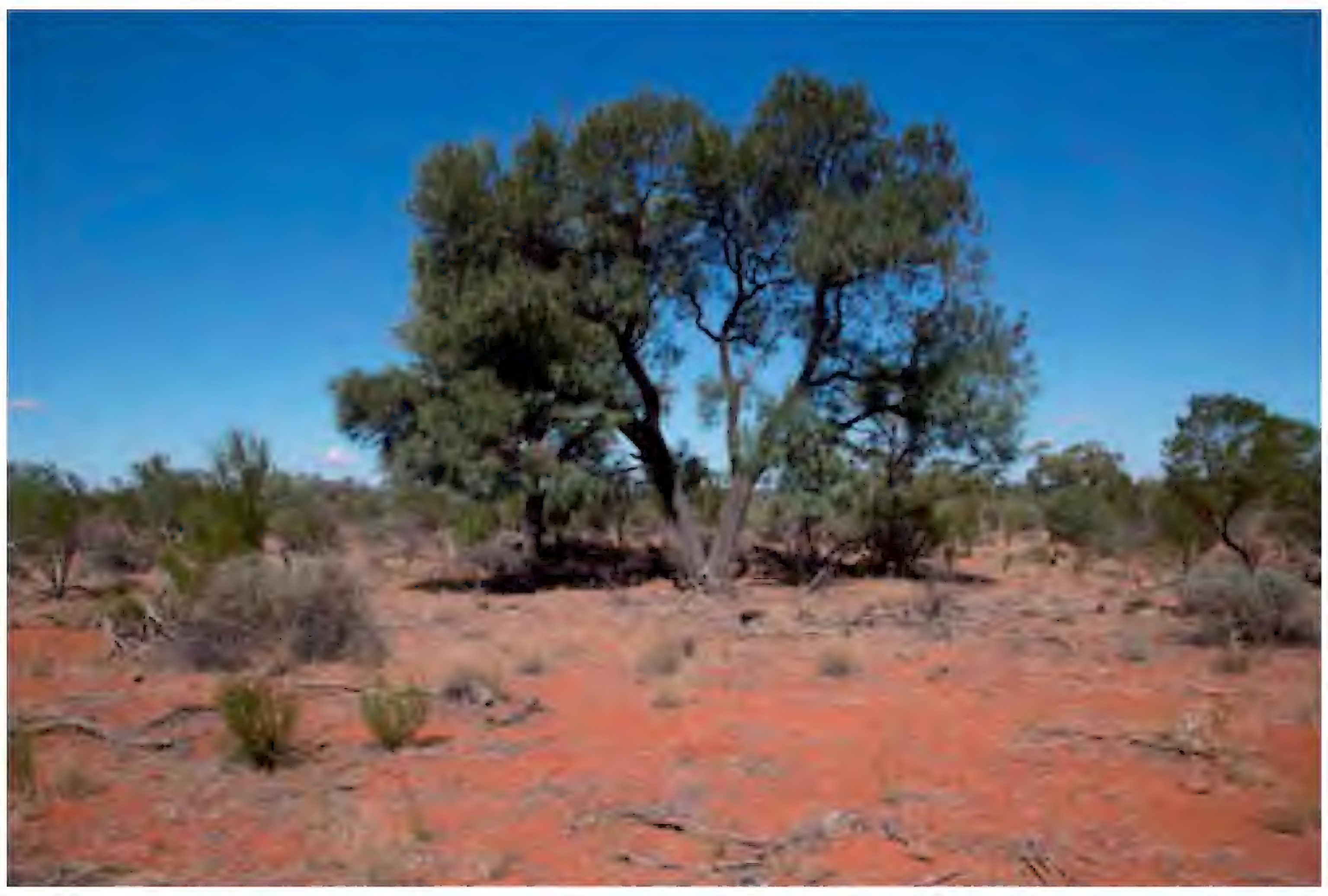

Fig. 14. Group 2: Shrubland Complex; Alliance 3: Turpentine – Hop Bush – Kerosine Grass Shrubland; Association 7: *Acacia excelsa – Flindersia maculosa – Ventilago viminalis* Shrubland.

Group 3: Floodplain Wetlands Complex

Common Overstorey: *Eucalyptus coolabah, Acacia stenophylla, Eucalyptus largiflorens, Eucalyptus ochrophloia, Eucalyptus populnea.*

Common Mid-storey: *Duma florulenta, Sclerolaena birchii, Teucrium racemosum, Myoporum montanum, Sclerolaena muricata, Acacia victoriae, Eremophila bignoniiflora.*

Common Understorey: *Sporobolus mitchellii, Eragrostis lacunaria, Paspalidium jubiflorum, Portulaca oleracea, Alternanthera nodiflora, Sporobolus caroli, Centipeda thespidioides, Solanum esuriale, Marsilea drummondii, Eleocharis pusilla, Glinus lotoides, Trianthema triquetra, Eragrostis dielsii, Dactyloctenium radulans, Chamaesyce drummondii, Atriplex eardleyae, Pterocaulon sphacelatum, Sporobolus actinocladus, Chenopodium melanocarpum, Cyperus gilesii, Atriplex angulata, Sida goniocarpa, Eragrostis australasica.*

Alliance 4: Coolibah – Black Box – Yapunyah – Lignum Woodlands

Common Overstorey: *Eucalyptus coolabah, Acacia stenophylla, Eucalyptus ochrophloia, Eucalyptus largiflorens.*

Common Mid-storey: *Duma florulenta, Sclerolaena birchii, Sclerolaena muricata, Myoporum montanum, Teucrium racemosum, Acacia victoriae, Eremophila bignoniiflora, Atriplex eardleyae, Atriplex angulata, Atriplex limbata.*

Common Understorey: *Sporobolus mitchellii, Eragrostis lacunaria, Paspalidium jubiflorum, Portulaca oleracea, Alternanthera nodiflora, Sporobolus caroli, Centipeda thespidioides, Marsilea drummondii, Eleocharis pusilla, Trianthema triquetra, Eragrostis dielsii, Dactyloctenium radulans, Chamaesyce drummondii, Solanum esuriale, Cyperus gilesii.*

Association 8: *Eucalyptus ochrophloia* (Yapunyah) – *Eucalyptus largiflorens* (Black Box) – *Acacia stenophylla* (River Cooba) Woodland and Forest (Fig. 15).

Environmental relationships: restricted primarily to frequently inundated locations, particularly along the margins of open floodplains and along ephemeral watercourses. The density of the overstorey tree layer is highly variable and this may not be distinct.

Structure: open shrubland to low open woodland or open woodland.

- Tree layer: (3-) 5-9 (-16) m tall. (5-) 20-25 (-45)% cover. Not always present.
- Shrub layer: (0.5-) 1-2.5 (-4) m tall. (2-) 10-15 (-30)% cover.
- Understorey layer: 0.1-0.2 (-1.5) m tall. (5-) 30-35 (-80)% cover.

Trees: *Eucalyptus ochrophloia, Eucalyptus largiflorens, Acacia stenophylla, Hakea tephrosperma, Eucalyptus coolabah, Acacia excelsa.*

Shrubs: *Duma florulenta, Sclerolaena birchii, Myoporum montanum, Eremophila bignoniiflora, Teucrium racemosum, Sclerolaena muricata, Atriplex eardleyae, Chenopodium auricomum, Acacia victoriae, Eremophila deserti, Hakea leucoptera, Sclerolaena decurrens, Eremophila glabra, Enchylaena tomentosa, Senna artemisioides* subsp. *zygophylla, Sclerolaena muricata, Eremophila sturtii, Atriplex leptocarpa.*

Climbers & trailers: none apparent.

Ground cover: *Sporobolus mitchellii, Paspalidium jubiflorum, Eragrostis lacunaria, Portulaca oleraceus, Marsilea drummondii, Centipeda thespidioides, Eleocharis pusilla, Sporobolus caroli, Cyperus gilesii, Alternanthera nodiflora, Solanum esuriale, Panicum laevinode, Juncus aridicola, Trianthema triquetra, Pterocaulon sphacelatum, Dactyloctenium radulans, Chamaesyce drummondii, Amaranthus macrocarpus, Enteropogon acicularis, Boerhavia repleta, Vittadinia sulcata, Solanum lacunarium, Sida goniocarpa, Sida filiformis, Pluchea tetranthera, Cynodon dactylon, Vittadinia pterochaeta, Streptoglossa adscendens, Pluchea dentex, Marsilea costulifera, Ludwigia peploides, Frankenia uncinata, Eriochloa australiensis, Eleocharis plana, Cyperus bifax, Centipeda minima, Brachyscome ciliaris, Alternanthera denticulata, Abutilon* *otocarpum, Tephrosia sphaerospora, Sida trichopoda, Sauropus trachyspermus, Phyllanthus virgatus, Leiocarpa semicalva, Hibiscus trionum, Haloragis glauca, Eragrostis australasica, Chamaesyce dallachyana, Brachyscome melanocarpa, Boerhavia coccinea, Aristida holathera.*

Introduced taxa: *Eragrostis cilianensis, Medicago truncatula, Medicago polymorpha, Malvastrum americanum.*

Association 9: *Eucalyptus coolabah* (Coolibah) – *Acacia stenophylla* (River Cooba) – *Eucalyptus ochrophloia* (Yapunyah) Woodland and Forest (Fig. 16).

Environmental relationships: commonly found in frequently inundated locations, particularly along the Cuttaburra Creek and within Yantabulla Swamp. Found in locations with more prolonged waterlogging than Association 8.

Structure: generally a woodland, layered shrubby woodland, tall layered shrubland or open to closed shrubland.

- Tree or tall shrub-layer: 4-7 (-12) m tall. (5-) 25-30 (-50)% cover.
- Shrub layer: (0.5-) 1.5-3 (-5) m tall. (5-) 25-30 (-70)% cover.
- Low shrub layer: 1-2.5 (-3) m tall. (25-) 40-45 (-70)% cover. Rarely present.
- Understorey layer: 0.1-0.7 (-2) m tall. (5-) 25-35 (-70)% cover.

Trees: *Eucalyptus coolabah, Acacia stenophylla, Eucalyptus ochrophloia, Atalaya hemiglauca, Eucalyptus largiflorens.*

Shrubs: *Duma florulenta, Sclerolaena muricata, Eremophila bignoniiflora, Sclerolaena birchii, Myoporum montanum, Atriplex eardleyae, Sclerolaena decurrens, Atriplex leptocarpa, Teucrium racemosum, Eremophila gilesii, Atriplex elachophylla, Hakea tephrosperma, Atriplex suberecta, Atriplex stipitata, Atriplex limbata, Atriplex angulata, Maireana brevifolia, Eremophila deserti.*

Climbers & trailers: none apparent.

Ground cover: *Sporobolus mitchellii, Paspalidium jubiflorum, Alternanthera nodiflora, Cyperus gilesii, Ammannia multiflora, Eragrostis lacunaria, Chamaesyce drummondii, Portulaca oleracea, Eleocharis pusilla, Centipeda thespidioides, Sporobolus caroli, Marsilea drummondii, Glinus lotoides, Pluchea dentex, Eragrostis australasica, Echinochloa inundata, Centipeda cunninghamii, Trianthema triquetra, Juncus aridicola, Hibiscus trionum, Haloragis glauca, Cyperus squarrosus, Centipeda crateriformis, Streptoglossa adscendens, Sporobolus actinocladus, Solanum esuriale, Pseudognaphalium luteoalbum, Eragrostis dielsii, Enteropogon acicularis, Eleocharis acuta, Einadia nutans, Cyperus iria, Vittadinia pterochaeta, Sida goniocarpa, Senecio magnificus, Pterocaulon sphacelatum, Phyllanthus lacunarius, Persicaria lapathifolia, Panicum laevinode, Epaltes australis, Dactyloctenium radulans, Cyperus difformis, Chenopodium melanocarpum, Centipeda minima, Boerhavia repleta, Amaranthus macrocarpus, Abutilon leucopetalum, Stemodia glabella, Solanum lacunarium, Solanum cleistogamum, Pluchea tetranthera, Ludwigia peploides, Goodenia glauca, Echinochloa turneriana, Cyperus bifax, Cynodon dactylon, Cullen cinereum, Alternanthera denticulata, Abutilon otocarpum.*

Introduced taxa: *Sisymbrium erysimoides, Malvastrum americanum, Heliotropium supinum, Cenchrus ciliaris, Potentilla supina, Medicago polymorpha, Eragrostis cilianensis, Citrullus lanatus.*

Alliance 5: Rat's-tail Couch – Lovegrass Grasslands

Common Overstorey: *Eucalyptus coolabah.*

Common Mid-storey: *Sclerolaena birchii, Teucrium racemosum, Acacia victoriae, Myoporum montanum, Duma florulenta.*

Common Understorey: *Sporobolus mitchellii, Eragrostis lacunaria, Portulaca oleracea, Eragrostis dielsii, Trianthema triquetra, Centipeda thespidioides, Alternanthera nodiflora, Dactyloctenium radulans, Atriplex angulata, Eleocharis pusilla, Chenopodium melanocarpum, Pratia darlingensis, Solanum esuriale, Sida goniocarpa, Marsilea drummondii, Atriplex limbata, Sclerolaena decurrens, Glinus lotoides, Chenopodium cristatum, Alternanthera denticulata, Paspalidium jubiflorum.*

Association 10: *Sporobolus mitchellii* (Rat's-tail Couch) – *Eragrostis lacunaria* (Purple Lovegrass) – *Sporobolus caroli* (Fairy Grass) Grassland and Herbfield (Fig. 17).

Environmental Relationships: found in areas where water ponding occurs but on lighter textured soils than Association 8 and 9.

Distribution within *Naree* and *Yantabulla*: throughout both properties in areas of water ponding.

Structure: usually an open to closed grassland, low open shrubland or open shrubland.

- Shrub layer: (0.8-) 2.5-4.5 (-9) m tall. (1-) 15-20 (-60)% cover. Often absent.
- Low layer: 1-2.5 (-3) m tall. 10-15 (-20)% cover. Rarely present.
- Understorey layer: 0.1-0.6 (-1) m tall. (5-) 40-45 (-90)% cover.

Trees: *Eucalyptus coolabah.*

Shrubs: *Sclerolaena birchii, Teucrium racemosum, Acacia victoriae, Myoporum montanum, Atriplex angulata, Duma florulenta, Atriplex limbata, Sclerolaena decurrens, Atriplex holocarpa, Atriplex eardleyae, Eremophila sturtii, Salsola australis, Atriplex elachophylla, Sclerolaena tricuspis, Enchylaena tomentosa, Sclerolaena diacantha, Sclerolaena bicornis, Olearia pimeleoides, Mairena brevifolia, Atriplex stipitata.*

Climbers & trailers: *Convolvulus remotus, Convolvulus clementii.*

Ground cover: *Sporobolus mitchellii, Eragrostis lacunaria, Portulaca oleracea, Sporobolus caroli, Eragrostis dielsii,* *Trianthema triquetra, Dactyloctenium radulans, Solanum esuriale, Marsilea drummondii, Eleocharis pusilla, Alternanthera nodiflora, Chloris truncata, Chamaesyce drummondii, Paspalidium jubiflorum, Enneapogon avenaceus, Chenopodium cristatum, Brachyscome ciliaris, Tetragonia eremaea, Rhynchosia minima, Pterocaulon sphacelatum, Frankenia uncinata, Fimbristylis dichotoma, Chenopodium melanocarpum, Centipeda thespidioides, Centipeda crateriformis, Pluchea tetranthera, Panicum decompositum, Lotus cruentus, Linum marginale, Glossostigma diandrum, Eriochloa australiensis, Eragrostis parviflora, Calotis hispidula, Brachyscome ciliaris, Wahlenbergia communis, Tragus australianus, Pratia darlingensis, Eragrostis australasica, Einadia nutans, Boerhavia repleta, Walwhalleya subxerophyllum, Stemodia glabella, Sporobolus actinocladus, Sida platycalyx, Sida goniocarpa, Sida filiformis, Pimelea trichostachya, Leiocarpa semicalva, Juncus aridicola, Glinus lotoides, Eragrostis brownii, Centipeda minima, Boerhavia dominii.*

Introduced taxa: *Eragrostis cilianensis, Malvastrum americanum, Medicago polymorpha, Cucumis myriocarpus, Malva parviflora, Xanthium occidentale, Sonchus oleraceus, Silene gallica, Lepidium bonariense, Cenchrus ciliaris.*

Association 11: *Sporobolus mitchellii* (Rat's-tail Couch) – *Eragrostis lacunaria* (Purple Lovegrass) – *Sporobolus caroli* (Fairy Grass) Grassland and Herbfield (Fig. 18).

Environmental relationships: found in areas of waterlogging but with higher clay content than Association 10.

Structure: usually an open grassland, grassland or open herbfield, more rarely a low open woodland.

- Tree-layer: 5-10 (-15) m tall. 10-15% cover. Usually absent.
- Understorey layer: 0.1-0.3 (-0.6) m tall. 15-30 (-70)% cover.

Trees: *Eucalyptus coolabah, Eucalyptus populnea.*

Shrubs: *Teucrium racemosum, Sclerolaena diacantha, Sclerolaena decurrens.*

Climbers & trailers: *Convolvulus remotus, Convolvulus clementii.*

Ground cover: *Sporobolus mitchellii, Portulaca oleracea, Eragrostis lacunaria, Sida goniocarpa, Stuartina muelleri, Glinus lotoides, Alternanthera denticulata, Abutilon otocarpum, Sida trichopoda, Chenopodium melanocarpum, Centipeda thespidioides, Alternanthera nodiflora, Dactyloctenium radulans, Abutilon oxycarpum, Stemodia glabella, Sporobolus caroli, Marsilea hirsuta, Eragrostis basedowii, Epaltes australis, Monachather paradoxus, Marsilea drummondii, Frankenia uncinata, Eragrostis dielsii, Centipeda minima, Bergia trimera, Wahlenbergia communis, Pluchea dentex.*

Introduced taxa: *Malvastrum americanum.*

Association 12: *Pratia darlingensis* (Darling Pratia) – *Sporobolus mitchellii* (Rat's-tail Couch) Herbfield and Grassland (Fig. 19).

Environmental relationships: found in locations where water ponding occurs, generally in areas with a higher sand context than Association 11.

Trees: *Eucalyptus populnea.*

Shrubs: *Hakea ivoryi, Teucrium racemosum, Sclerolaena birchii, Senna artemisioides* subsp. *zygophylla, Sclerolaena muricata, Sclerolaena convexula, Eremophila longifolia, Dodonaea viscosa, Acacia victoriae, Acacia aneura.*

Climbers & trailers: none apparent.

Ground cover: *Pratia darlingensis, Sporobolus mitchellii, Eleocharis pusilla, Centipeda thespidioides, Alternanthera nodiflora, Sporobolus caroli, Solanum cleistogamum, Paspalidium jubiflorum, Cyperus squarrosus, Chenopodium melanocarpum, Sporobolus actinocladus, Eragrostis parviflora, Eragrostis lacunaria, Cyperus iria, Alternanthera denticulata, Solanum esuriale, Sida goniocarpa, Panicum laevinode, Marsilea costulifera, Eragrostis dielsii, Eleocharis pallens, Cynodon dactylon, Chamaesyce drummondii, Calotis cuneifolia, Boerhavia repleta.*

Introduced taxa: *Eragrostis cilianensis.*

Alliance 6: Canegrass Grassland

Alliance 13: *Eragrostis australasica* (Canegrass) Grassland (Fig. 20).

Environmental relationships: restricted to frequently inundated and water ponding areas, often with a fine silty clay content.

Structure: a grassland to open grassland.

- Upper layer: 0.8-2.5 m tall. 10-80% cover.
- Understorey layer: 0.1-1 m tall. 5-30 (-70)% cover.

Trees: none apparent.

Shrubs: *Atriplex eardleyae, Atriplex stipitata, Duma florulenta, Atriplex angulata.*

Climbers & trailers: none apparent.

Ground cover: *Eragrostis australasica, Panicum decompositum, Sporobolus mitchellii, Eleocharis pusilla, Centipeda crateriformis, Portulaca oleracea.*

Introduced taxa: none apparent.

Alliance 7: Lignum – Glinus Shrubland

Association 14: *Glinus lotoides* (Glinus) – *Senecio runcinifolius* (Groundsel) – *Duma florulenta* (Lignum) Herbfield and Shrubland (Fig. 21).

Environmental relationships: restricted to flooded and ponding areas generally on heavier clays.

Structure: an open herbaceous shrubland or open to closed herbfield.

- Upper layer: 1-2.5 m tall. 40-80% cover. Usually absent.
- Understorey layer: 0.1-1.5 m tall. 5-70% cover.

Trees: *Eucalyptus coolabah, Acacia stenophylla.*

Shrubs: *Duma florulenta, Myoporum montanum, Sclerolaena birchii, Dodonaea viscosa.*

Climbers & trailers: none apparent.

Ground cover: *Glinus lotoides, Senecio runcinifolius, Centipeda minima, Sporobolus mitchellii, Centipeda cunninghamii, Centipeda crateriformis, Epaltes australis, Alternanthera nodiflora, Pterocaulon sphacelatum, Marsilea costulifera, Cyperus squarrosus, Centipeda thespidioides, Ammannia multiflora, Amaranthus grandiflorus, Alternanthera angustifolia, Stemodia glabella, Sporobolus caroli, Ludwigia peploides, Juncus aridicola, Dactyloctenium radulans, Cynodon dactylon, Chenopodium melanocarpum.*

Introduced taxa: *Heliotropium supinum, Citrullus lanatus, Cucumis myriocarpus, Argemone ochroleuca.*

Alliance 8: Poplar Box – Black Box Woodland

Common Overstorey: *Eucalyptus populnea, Eucalyptus largiflorens.*

Common Mid-storey: *Teucrium racemosum, Senna artemisioides* subsp. *zygophylla, Eremophila sturtii, Senna artemisioides* subsp. *filifolia, Sclerolaena birchii, Eremophila longifolia, Eremophila deserti, Myoporum montanum, Eremophila goodwinii.*

Common Understorey: *Enteropogon acicularis, Eragrostis lacunaria, Solanum esuriale, Sporobolus actinocladus, Paspalidium jubiflorum, Centipeda thespidioides, Sporobolus caroli, Marsilea drummondii, Cyperus iria, Wahlenbergia gracilis, Sida trichopoda, Eriochloa australiensis, Chloris truncata, Chenopodium melanocarpum, Marsilea costulifera, Digitaria brownii.*

Association 15: *Eucalyptus populnea* Woodlands (Fig. 22).

Environmental relationships: often on minor and ephemeral drainage lines associated within Mulga lands (Group 1). Also found on duplex soils between dunal or red clays and grey to black cracking clays of floodplains.

Structure: generally a low woodland or shrubby low woodland.

- Tree-layer: (3-) 5-10 (-16) m tall. (10-) 20-25 (-50)% cover.
- Shrub layer: 1-2.5 (-3) m tall. (5-) 15-25 (-70)% cover.
- Understorey layer: 0.1-0.7 (-1.8) m tall. (10-) 30-35 (-60)% cover.

Trees: *Eucalyptus populnea, Acacia aneura, Eucalyptus coolabah.*

Shrubs: *Senna artemisioides* subsp. *zygophylla, Senna artimisioides* subsp. *filiformis, Teucrium racemosum, Sclerolaena birchii, Eremophila sturtii, Eremophila longifolia, Eremophila deserti, Myoporum montanum, Eremophila goodwinii, Sclerolaena convexula, Eremophila glabra, Dodonaea viscosa, Eremophila gilesii, Dichanthium sericeum, Amaranthus macrocarpus, Abutilon oxycarpum, Tripogon loliiformis, Trianthema triquetra, Solanum ellipticum, Solanum cinereum, Pluchea tetranthera, Panicum effusum, Panicum decompositum, Evolvulus alsinoides, Eragrostis setifolia, Eragrostis microcarpa, Eragrostis brownii, Enneapogon avenaceus, Elytrophorus spicatus, Centipeda minima, Centipeda crateriformis, Boerhavia repleta, Aristida jerichoensis.*

Climbers & trailers: *Convolvulus clementii.*

Ground cover: *Enteropogon acicularis, Sporobolus actinocladus, Solanum esuriale, Centipeda thespidioides, Paspalidium jubiflorum, Sporobolus caroli, Alternanthera nodiflora, Eragrostis lacunaria, Cyperus iria, Calandrinia eremaea, Wahlenbergia gracilis, Sida trichopoda, Pterocaulon sphacelatum, Eriochloa australiensis, Chenopodium melanocarpum, Abutilon otocarpum, Sporobolus mitchellii, Marsilea drummondii, Marsilea costulifera, Digitaria brownii, Chloris truncata, Stemodia glabella, Phyllanthus virgatus, Eragrostis parviflora, Eleocharis pusilla, Alternanthera denticulata, Aristida holathera.*

Introduced taxa: *Malvastrum americanum, Eragrostis cilianensis, Verbena gaudichaudii, Silene gallica, Cucumis myriocarpus, Citrullus lanatus.*

Association 16: *Eucalyptus largiflorens* (Black Box) Woodland (Fig. 23).

Environmental relationships: found on low lying areas that are periodically flooded. Usually around the upper margins of lake beds or within islands internal to the lakes. Often forming dense stands due to mass germination after waters recede.

Structure: generally a low open woodland, low woodland or a dense shrubland (due to young cohort regeneration).

- Tree-layer: (3-) 4.5-8 (-10) m tall. (20-) 40-45 (-70)% cover.
- Shrub layer: (0.5-) 0.8-2 (-3) m tall. 5-10% cover. Rarely present.
- Understorey layer: 0.1-0.4 (-1) m tall. (5-) 30-35 (-80)% cover.

Trees: *Eucalyptus largiflorens, Eucalyptus populnea.*

Shrubs: *Teucrium racemosum, Eremophila sturtii, Sclerolaena birchii, Hakea leucoptera, Dodonaea viscosa, Atriplex eardleyae.*

Climbers & trailers: none apparent.

Ground cover: *Eragrostis lacunaria, Enteropogon acicularis, Stemodia glabella, Solanum esuriale, Pterocaulon sphacelatum, Sporobolus mitchellii, Paspalidium jubiflorum, Sporobolus caroli, Portulaca oleracea, Marsilea drummondii, Calandrinia eremaea, Brachyscome ciliaris, Boerhavia coccinea, Vittadinia cuneata, Sida goniocarpa, Sclerolaena birchii, Sauropus trachyspermus, Linum marginale, Leptorhynchos baileyi, Eragrostis dielsii, Einadia nutans, Chloris truncata, Chamaesyce drummondii, Alternanthera nodiflora.*

Introduced taxa: *Malvastrum americanum, Eragrostis cilianensis.*

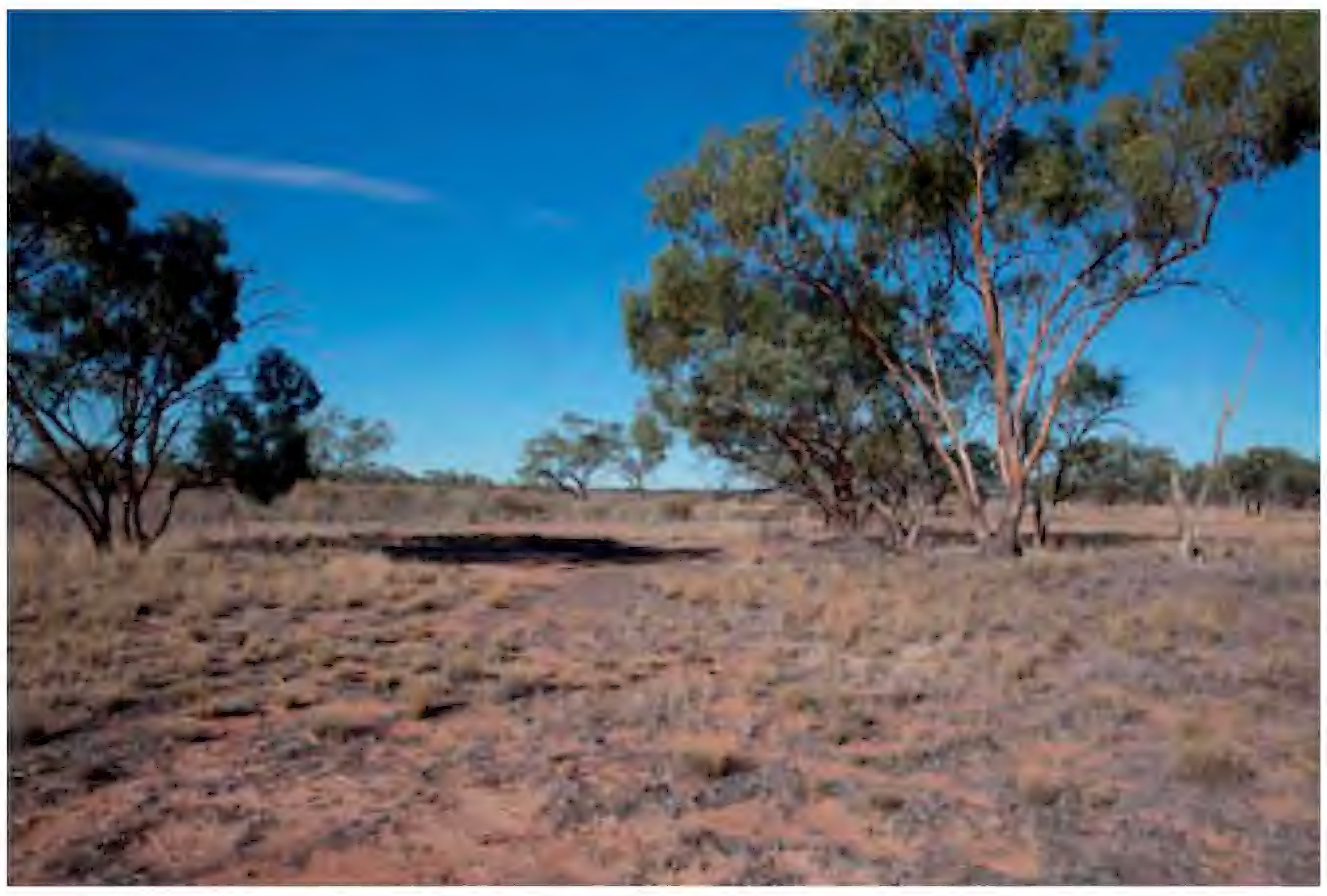

Fig. 15. Group 3: Floodplain Wetlands Complex; Alliance 4: Coolibah – Black Box – Yapunyah – Lignum Woodlands; Association 8: *Eucalyptus ochrophloia – Eucalyptus largiflorens – Acacia stenophylla* Woodland and Forest.

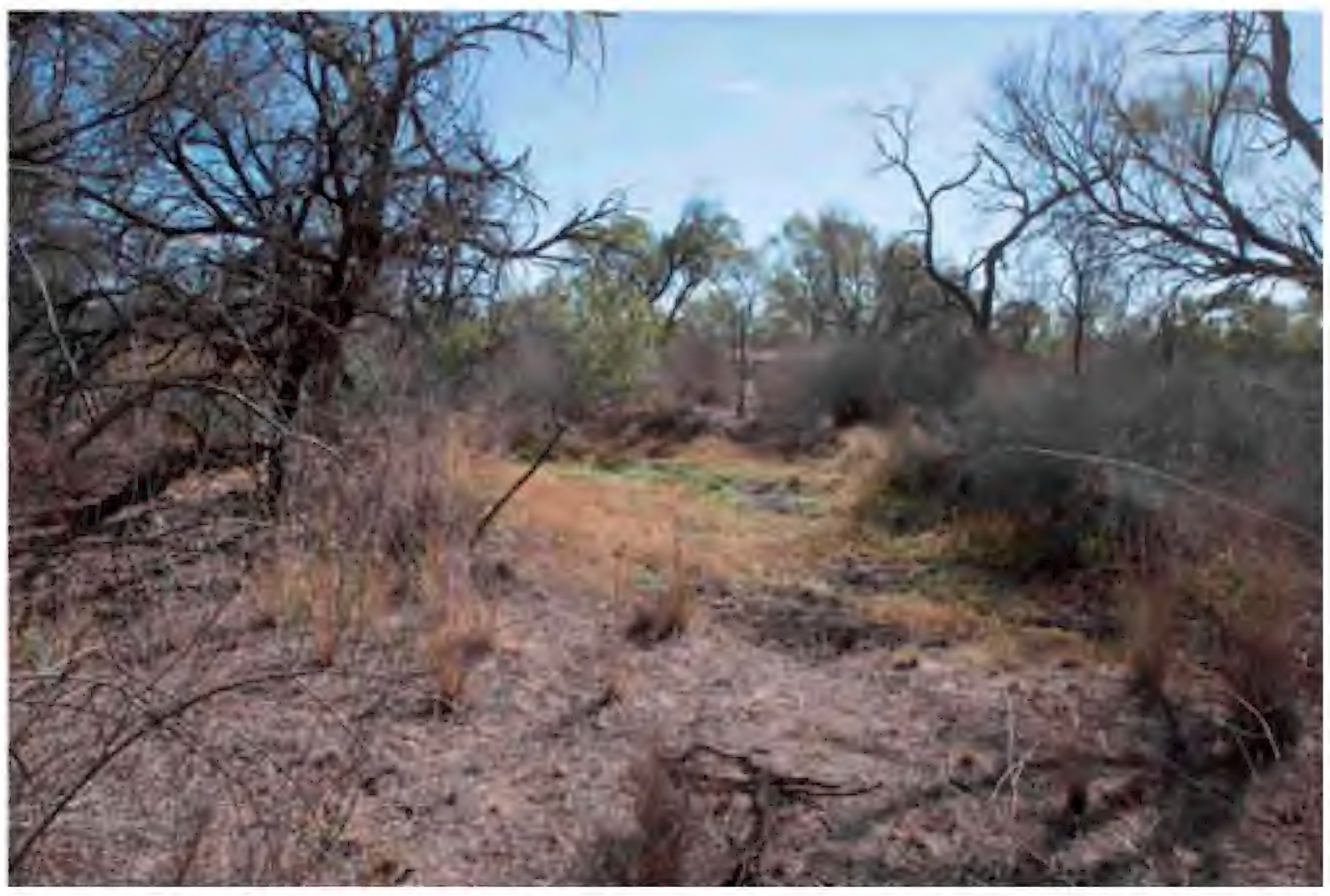

Fig. 16. Group 3: Floodplain Wetlands Complex; Alliance 4: Coolibah – Black Box – Yapunyah – Lignum Woodlands; Association 9: *Eucalyptus coolabah – Acacia stenophylla – Eucalyptus ochrophloia* Woodland and Forest.

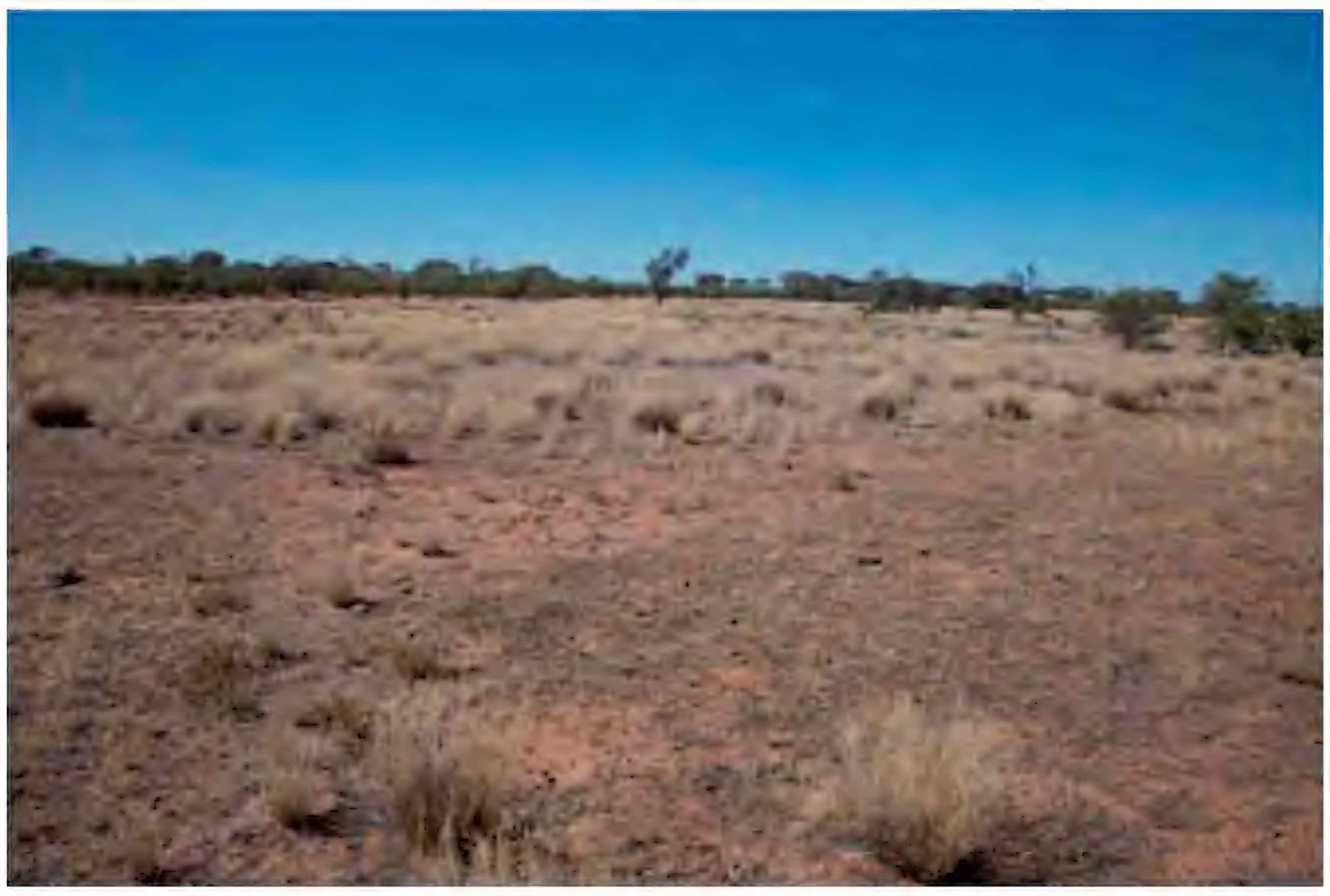

Fig. 17. Group 3: Floodplain Wetlands Complex; Alliance 5: Rat's-tail Couch – Lovegrass Grasslands; Association 10: *Sporobolus mitchellii – Eragrostis lacunaria – Sporobolus caroli* Grassland and Herbfield.

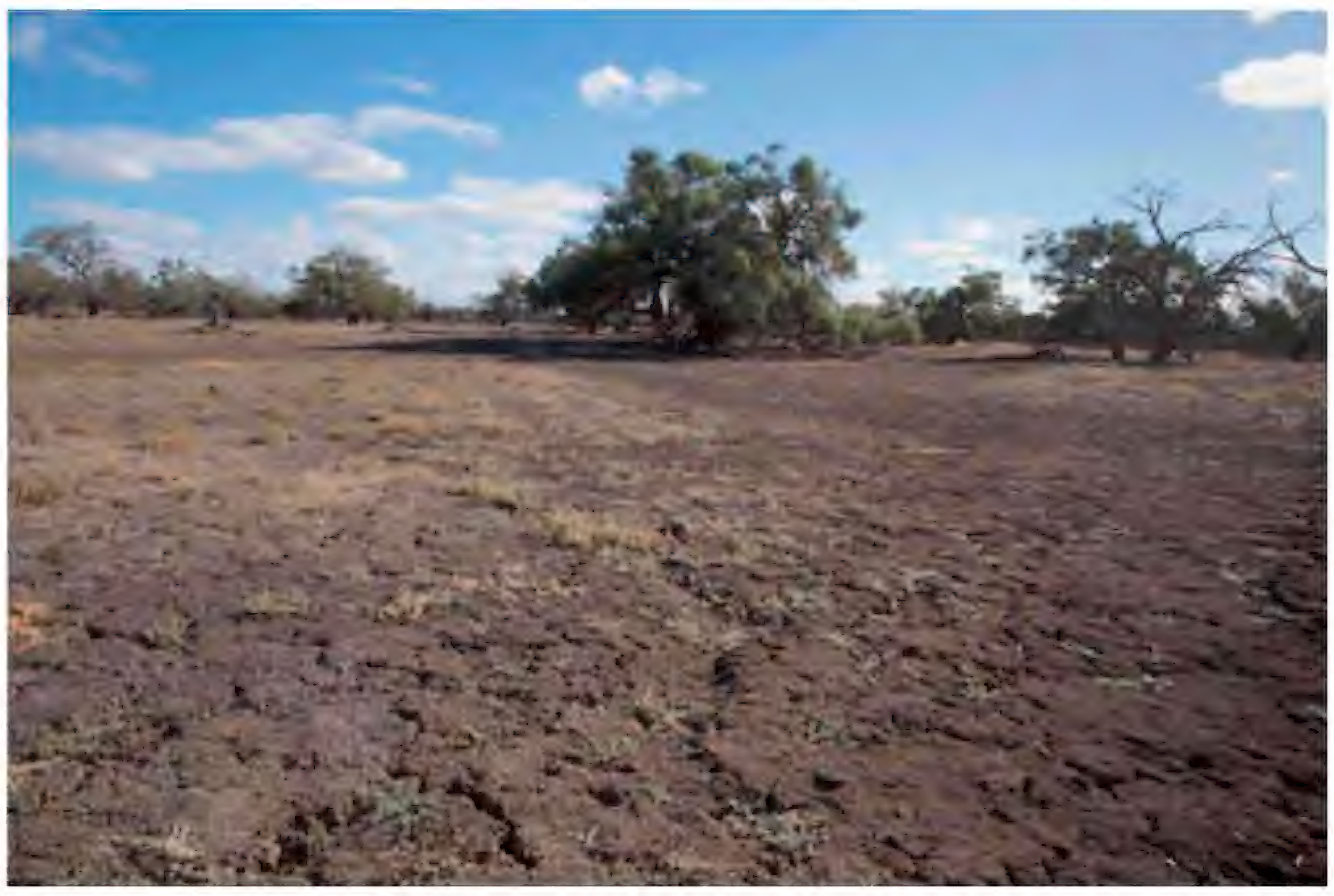

Fig. 18. Group 3: Floodplain Wetlands Complex; Alliance 5: Rat's-tail Couch – Lovegrass Grasslands; Association 11: *Sporobolus mitchellii – Eragrostis lacunaria* Grassland and herbfield.

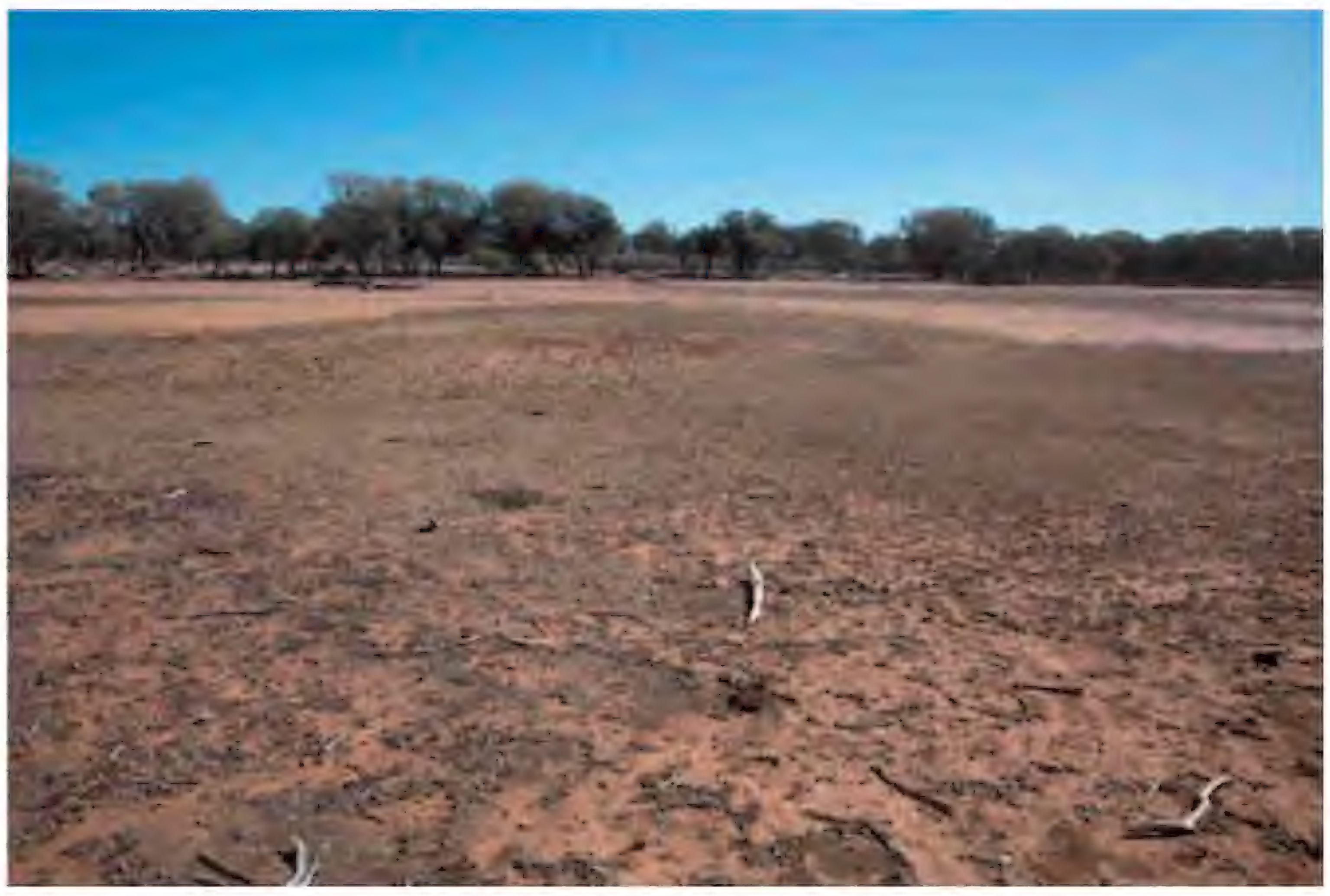

Fig. 19. Group 3: Floodplain Wetlands Complex; Alliance 5: Rat's-tail Couch – Lovegrass Grasslands; Association 12: *Pratia darlingensis – Sporobolus mitchellii* Herbfield and Grassland.

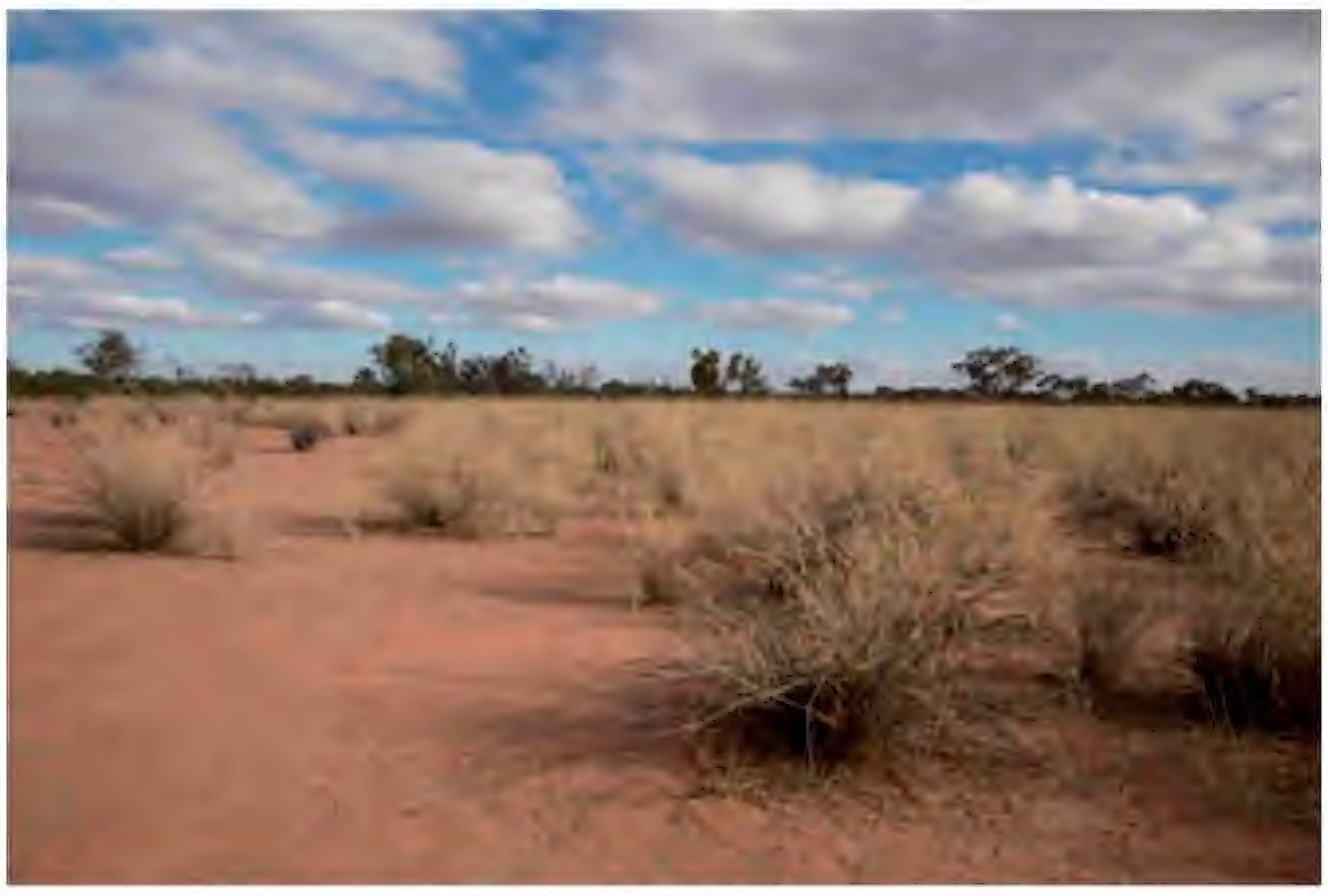

Fig. 20. Group 3: Floodplain Wetlands Complex; Alliance 6: Canegrass Grassland; Association 13: *Eragrostis australasica* Grassland.

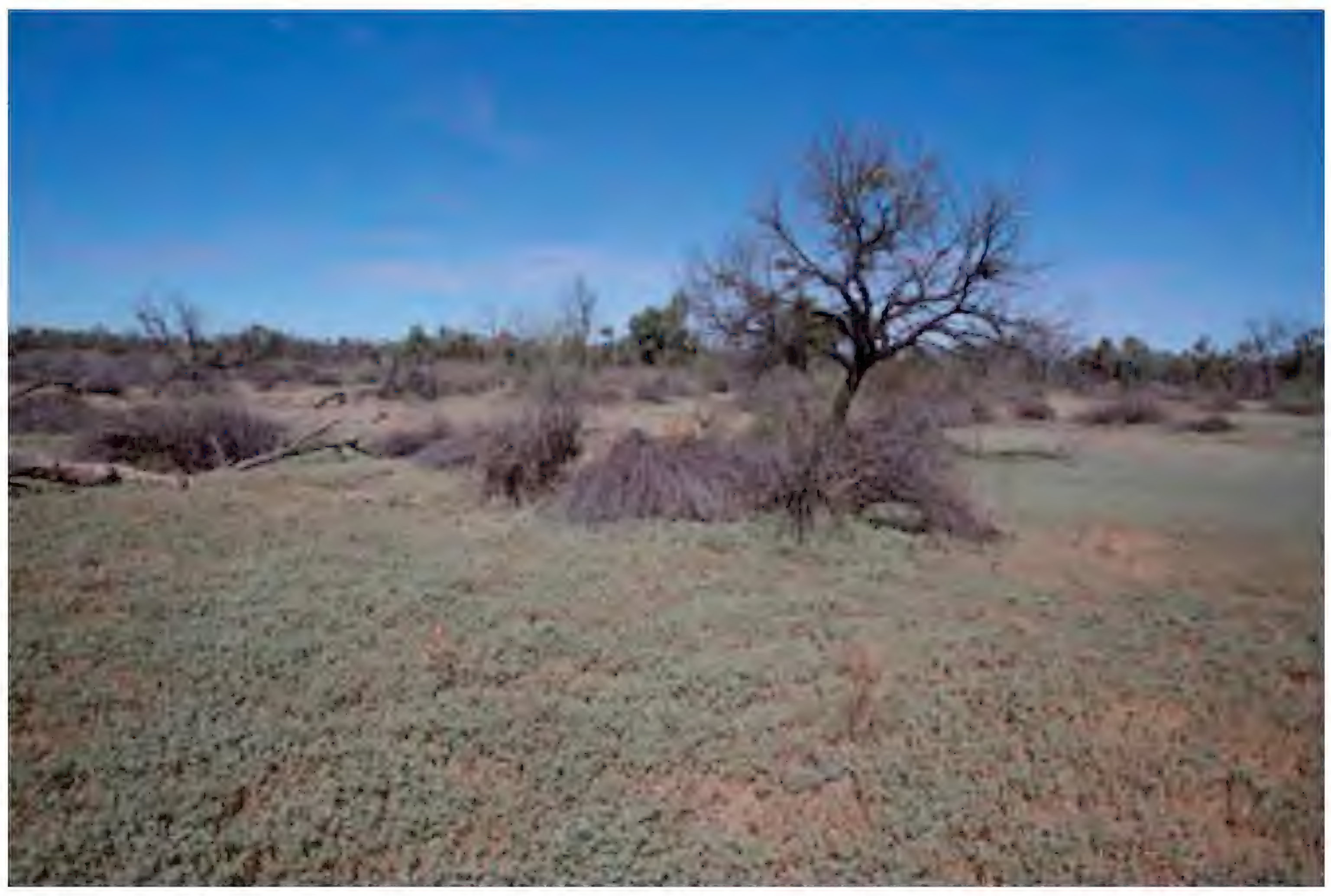

Fig. 21. Group 3: Floodplain Wetlands Complex; Alliance 7: Lignum – Glinus Herbfield and Shrubland; Association 14: *Glinus lotoides – Senecio runcinifolius – Duma florulenta* Herbfield an Shrubland.

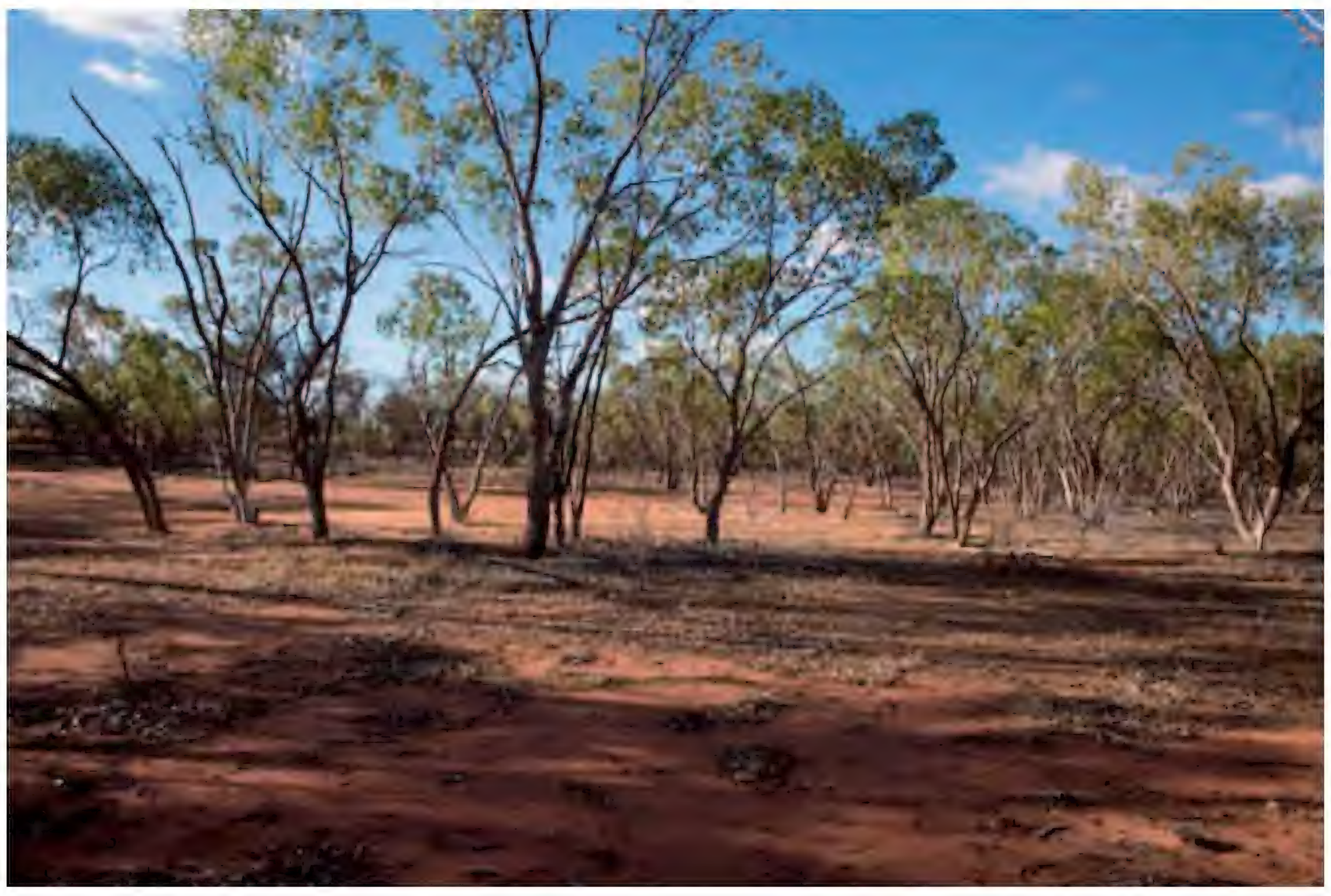

Fig. 22. Group 3: Floodplain Wetlands Complex; Alliance 8: Poplar Box – Black Box Woodland; Association 15: *Eucalyptus populnea* Woodland.

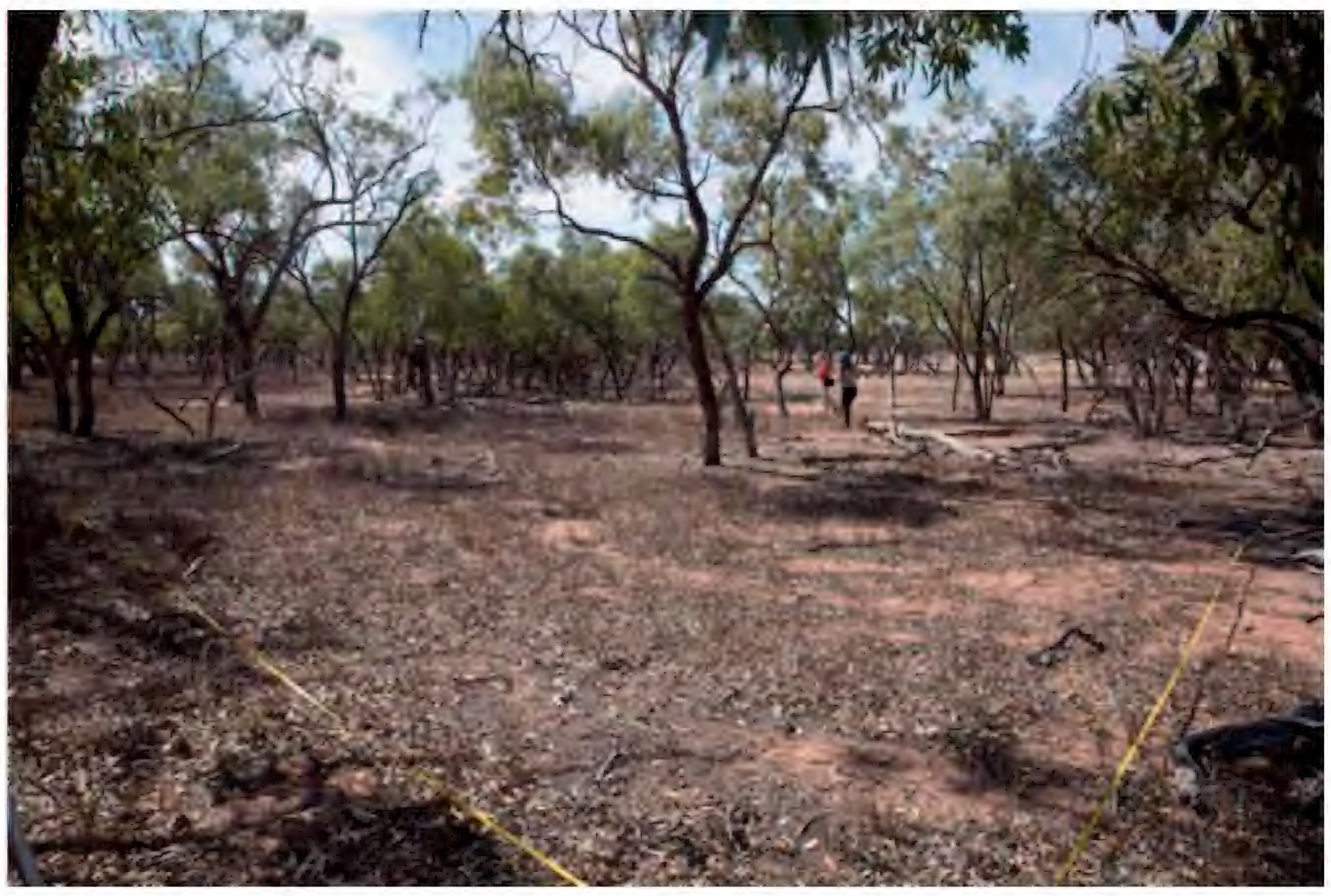

Fig. 23. Group 3: Floodplain Wetlands Complex; Alliance 8: Poplar Box – Black Box Woodland; Association 16: *Eucalyptus largiflorens* Woodland.

Discussion

Significant plant species

Dentella minutissima (family Rubiaceae) is the only flora species currently listed as endangered on the New South Wales *Threatened Species Conservation* Act (*TSC* Act). *Dentella minutissima* has been previously recorded within Nocoleche Nature Reserve, Toorale National Park, Toorale State Conservation Area. *Dentella minutissima* is restricted to mudflats around drying waterholes or sandy silts on the edge of drainage lines. Due to the ephemeral flowering and size of the species there may be additional populations across both properties. Other taxa of significance include *Potentella nanopetala* (Rosaceae), which is currently known from two NSW populations and may be a candidate for *TSC* Act listing. *Eucalyptus melanophloia* (Myrtaceae), *Brachychiton populneus* (Sterculiaceae) and *Dodonaea boroniifolia* (Sapindaceae) are all at their western limit of distribution on the *Naree* and *Yantabulla* properties.

Rainfall and periodic recruitment

In arid and semi-arid assemblages the composition and turnover of annual and shortlived perennial species varies from year to year (Porteners *et al.* 1997). The presence and detectability of the many groundlayer taxa is determined by the amount and seasonal distribution of rainfall (Fox 1991) and/or flooding events. Different frequencies of flooding and its duration are known to significantly alter the dominant species of these systems. Grasslands can turn to shrublands and vice versa and trees such as *Eucalyptus largiflorens, Eucalyptus coolabah* and *Eucalyptus populnea* can regenerate in large cohorts or suffer extensive dieback. Thus understories may have significant mosaic shifts in their ephemeral floras in the short term with encroachments and retractions of some overstorey species in the long term. While the floristic analysis and mapping in this study is largely based on one season, the resolution of mapping and delineation of units is believed to have occurred at a level that would not be highly influenced by these seasonal changes. Furthermore permanent plots were visited over a three year period to check consistency.

Population sizes of a number of taxa found dominating overstoreys within the study area (*Acacia aneura, Acacia oswaldii, Alectryon oleifolius, Atalaya hemiglauca, Casuarina pauper, Flindersia maculata, Grevillea striata, Hakea ivoryi, Hakea tephrosperma, Hakea leucoptera & Ventilago viminalis*) appear to be changing little demographically across the semi-arid regions of Australia (Parsons 1989; Batty & Parsons 1992; Auld & Denham 2001). A number of these taxa are likely to have evolved within the arid and semi-arid regions of Australia when the climate was warmer, more seasonal and more densely vegetated (Cretaceous-Palaeocene) (Specht & Specht 1999). All of these species are generally restricted to associations within Group 1 and in particular Group 2, which occur on the ancient nutrient poor red to brown earths and aeolian deposits. Many of these taxa in western New South Wales regenerate primarily by suckering, this can be seen readily in stands of *Alectryon* and *Hakea* which show obvious clumping and many exposed root systems. Recruitment via seed is considered a rare event for many overstorey species in arid and semi-arid regions with seedlings often decimated by rabbits and other introduced herbivores (Auld & Denham 2001). Even *Acacia aneura* is thought to only successfully establish once in every six years with germination requiring lower temperatures and good rains in summer and winter (Preece 1971; Burrows 1972; Beadle 1981; Boyland 1984). During the surveys some of these overstorey taxa (e.g. *Atalaya hemiglauca, Flindersia maculosa, Hakea ivoryi* and *Grevillea striata*) showed visible seedling germination in 2014 and 2015 within *Naree,* where feral animal control and stock removal had occurred since 2013, but many succumbed to the drier conditions of 2016 (*pers. obs.*). These relictual dominants within the shrublands are common within the sub-humid woodlands of arid and semi-arid Australia in marginal summer rainfall locations. These dominants become less prominent further south within NSW as rainfall becomes more aseasonal or winter dominant. The unpredictable rainfall, lack of seasonality, and increase in aridity that has occurred over millennia in this region of NSW is likely to play a major role in the lack of recruitment in these taxa, which often require a succession of good rainfall seasons, or have survived largely through asexual reproduction. Within the rangelands substantial changes in summer and autumn rainfall are predicted, with an increase in the dominance of warm season rainfall (CSIRO & Bureau of Meteorology 2015). Increasing unpredictability of weather, and increased temperatures and evapotranspiration exacerbating dry times, are likely to further reduce the chances of good recruitment for many of these taxa under anthropogenic climate change.

Importance of shrub vegetation

Floristic Group 2 (Fig. 4) comprises a number of shrub associations that are largely dominated by species thought to have increased in distribution since clearing and grazing was introduced. Such taxa include *Dodonaea viscosa* and *Eremophila sturtii* which are often termed ‘woody weeds’, with anecdotal evidence suggesting dense stands have higher erosion and reduced species diversity (Porteners *et al.* 1997). Such anecdotal evidence has led to managers believing that areas of ‘woody weed’ encroachment require intensive management to reduce their density. Initial plans for *Naree* had included control of ‘woody weeds’ (David & Sue Akers, Bush Heritage, *pers. comm.*); however others have found little evidence for increased erosion and their presence is not thought to cause any problems with respect to biodiversity (Pickard & Norris 1994; West 2000). While speculation about the effects of this transition have centred on shrub encroachment being a form of desertification or landscape degradation there has been little or no empirical support to suggest this is actually the case. The body of evidence suggests that woody encroachment in western NSW is largely a beneficial process that improves landscape health and soil function on almost all measured variables, and is neutral on others (Elkins *et al.* 1986; Bhark & Small 2003; Eldridge & Fruedenberger 2005; Maestre *et al.* 2009; Eldridge *et al.* 2011; Smith 2013; Daryanto *et al.* 2012; Daryanto *et al.* 2013; Howard *et al.* 2012; Eldridge *et al.* 2013; Soliveres & Eldridge 2013; Eldridge & Soliveres 2014; Eldridge *et al.* 2014; Soliveres *et al.* 2014; Eldridge *et al.* 2015). In 35 study sites across western NSW no declines in plant, vertebrate or invertebrate richness was found with increasing woody encroachment (Ayres *et al.* 2001). Grazing by stock was found to be the cause of any recorded decline in functionality of soils, productivity or landscape serviceability, while shrubs largely ameliorate the overgrazing damage (Eldridge *et al.* 2013; Eldridge & Soliveres 2015; Eldridge *et al.* 2015). Data from sites where goats and rabbits have been controlled indicate that shrub densities have a much lower impact on grass biomass than grazing (Robson 1995; Daryanto & Eldridge 2010). The state and transition model presented by Eldridge and Soliveres (2015) suggests that intensive grazing and mechanical removal of ‘woody weeds’ may lead to very dense shrublands with highly modified soil characteristics that could take up to 100 years to naturally recover, even with the removal of grazing and good rainfall. Moderately dense shrubland with a sparse understorey, however, may only require 10 years to return to a diverse state with a rich understorey, without blade ploughing and the exclusion of grazing, depending on seed banks and rainfall (Eldridge & Soliveres 2015). Shrublands with open to moderate shrub density and dominated by more than one species, with a stable soil surface, provide the highest overall ecosystem service values (Eldridge & Soliveres 2015). Eldridge *et al.* (2011) clearly state that shrub encroachment must be decoupled from the concept of degradation. Thus shrub encroachment across large areas of Group 2 within the *Naree* and *Yantabulla* study area should not automatically be viewed as an issue causing lowered biodiversity values.

Microhabitats

Litter and logs form important microhabitats for fauna species, germination sites for flora and at times allow protection of flora from grazing and browsing impacts. Thus litter and logs offer shelter, basking and foraging sites for fauna (Croft *et al.* 2011; 2015). Not only are tree hollows important for nesting species, they can also be sites for stored water within an otherwise dry landscape (Vickers *et al.* 2014). These features along with hollows in logs and trees form important components of functional resources that alter faunal abundance and composition (McElhinny *et al.* 2006; Croft *et al.* 2011; 2015; Hunter 2015a). The aim of this research was to provide limited baseline information in regards to the assemblages contained herein, however some generalisations can be made about these important functional attributes. The greatest proportion of logs on the ground is found within Alliance 1, the Mulga Complex. However, this may largely be artificial and related to previous land management practices of mulga pushing during drought times for fodder. The high score for logs within Alliance 2 was due to past clearing activities. Thus, these high scores may be much lower in natural or more mature stands and we might expect the current scores to reduce over time. Overall high abundance of tree hollows, natural logs on ground, litter weight and log hollows were primarily associated with the margins of wetlands and within floodplains such as Alliance

4 and Alliance 8 which is not surprising as these systems occur in the most productive areas of the landscape, being both on higher nutrient soils (clays) that receive and contain higher levels of water. *Acacia anuera* which dominates Alliance 1 contains a large number of natural hollows within the more mature stands along with a moderately high litter weight.

Naree and *Yantabulla* are part of an increasing network of privately purchased properties owned by organisations committed to managing lands for the primary purpose of rehabilitation and conservation. Private conservation lands are important places that augment our state and national reserve systems and may eventually rival government-controlled lands in size and diversity. They are also locations which are decoupled from political whims and public pressure that often infiltrate the management of government controlled reserves. Often this pressure comes from those who may not have a full understanding of the best science, leading to directives for management actions that are contrary to the conservation of biodiversity, or where biodiversity takes an important but none-the-less subsidiary role to other interests or concerns (Croft *et al.* 2016). While the government-controlled reserve network aspires to using the best available information it is often influenced by non-biodiversity priorities, and a lack of appropriate funds and staff. These privately managed lands may offer alternative and more flexible management styles that allow quicker adaptation to new management information and research results.

Acknowledgements

The authors wish to thank Dana Vickers and Sandy Gilmour for assistance in the field. Bush Heritage and South Endeavour Trust are thanked for allowing access to their lands. David and Sue Akers, managers of *Naree* and *Yantabulla* are also thanked for facilitating and assisting in all areas of this investigation.

References

Auld, T.D. & Denham, A.J. (2001) Flora conservation issues at Kinchega National Park, western NSW. *Cunninghamia* 7: 27-41.

Ayers, D., Melville, G., Bean, J., Beckers, D., Ellis, M., Mazzer, T., & Freudenberger, D. (2001) *Woody weeds, biodiversity and landscape function in western New South Wales.* WEST 2000 woody weeds and biodiversity project. (WEST 2000; Dubbo).

Batty, A.L. & Parsons, R.F. (1992) Regeneration of *Acacia melvillei* in part of semi-arid south-eastern Australia. *Proceedings of the Royal Society of Victoria* 104: 89-97.

Beadle, N.C.W. (1981) *The Vegetation of Australia*. (Cambridge University Press: Cambridge).

Belbin, L. (1995a) *Users Guide: PATN Pattern Analysis Package*. (Division of Wildlife & Ecology CSIRO: Canberra).

Belbin, L. (1995b). *Technical Reference: PATN Pattern Analysis Package.* (Division of Wildlife & Ecology CSIRO: Canberra).

Boyland, D.E. (1984) Vegetation survey of Queensland – south-western Queensland. *Queensland Botanical Bulletin* No. 4 (Queensland Department of Primary Industries: Brisbane).

Burrows, W.H. (1972) Productivity of an arid zone shrub (*Eremophila gilesii*) Community in south-western Queensland. *Australian Journal of Botany* 20: 317-329.

Colwell, R.K. (2006) *EstimateS*: Statistical estimation of species richness and shared species from samples. Version 8. (University of Connecticut, USA).

Croft, P., Hunter, J.T. & Reid, N. (2016) Forgotten fauna: habitat attributes of long unburnt open forests and woodlands dictate a rethink of fire management theory and practice. *Forest Ecology and Management* 366: 166-174.

Croft, P.J., Reid, N. & Hunter, J.T. (2011) Experimental burning changes the quality of fallen timber as habitat for vertebrate and invertebrate fauna: implications for fire management. *Wildlife Research* 37: 574-581.

CSIRO and Bureau of Meteorology (2015) *Climate Change in Australia information for Australia's Natural Resource Management Regions: Technical Report.* Department of Environment and Bureau of Meteorology, Australia.

Daryanto, S., Eldridge, D.J. & Throop, H.L. (2013) Managing semi-arid woodlands for carbon storage: grazing and shrub effects on above- and below ground carbon. *Agriculture, Ecosystems and Environment* 169: 1-11.

Daryanto, S., Eldridge, D.J. & Wang, L. (2013) Ploughing and grazing alter the spatial patterning of surface soils in a shrub-encroached woodland. *Geoderma* 200-201: 67-76.

Eldridge, D.J. (1998) Trampling of microphytic crusts on calcareous soils and its impact on erosion under rain-impacted flow. *Catena* 33: 221-239.

Eldridge, D.J. & Rath, D. (2002) Hip holes: kangaroo resting sites enhance the physical and chemical environment of woodland soils. *Austral Ecology* 27: 527-536.

Eldridge, D.J. & Freudenberger, D. (2005) Ecosystem wicks: woodland trees enhance water infiltration in a fragmented agricultural landscape in eastern Australia. *Austral Ecology* 30: 336-347.

Eldridge, D.J., Beecham, G. & Grace, J.B. (2015) Do shrubs reduce the adverse effects of grazing on soil properties? *Ecohydrology* 8: 1503-1513.

Eldridge, D.J., Wang, L. & Ruiz-Colmenero, M. (2015) Shrub encroachment alters the spatial patterns of infiltration. *Ecohydrology* 8: 83-93.

Eldridge, D.J., Soliveres, S., Bowker, M.A. & Val, J. (2013) Grazing dampens the positive effects of shrub encroachment on ecosystem functions in a semi-arid woodland. *Journal of Applied Ecology* 50: 1028-1038.

Eldridge, D.J., Bowker, M.A., Maestre, F.T., Roger, E., Reynolds, J.F. & Whitford, W.G. (2011) Impacts of shrub encroachment on ecosystem structure and functioning: towards a global perspective. *Ecology Letters* 14: 709-722.

Eldridge, D.J. & Soliveres, S. (2014) Are shrubs really a sign of declining ecosystem function? Disentagling the myths and truths of woody encroachment in Australia. *Australian Journal of Botany* 62: 594-608.

Elkins, N.Z., Sabol, G.V., Ward, T.J., Whitford, W.G. (1986) The influence of subterranean termites on the hydrological characteristics of a Chihuahuan desert ecosystem. *Oecologia* 68: 521-528.

Faber-Langendoen, D., Keeler-Wolf, T., Meidinger, D., Tart, D, Hoagland, B, Josse, C, Navarro, G., Ponomarenko, S., Saucier, J-P., Weakley, A & Comer, P. (2014) EcoVeg: a new approach to vegetation description and classification. *Ecological Monographs* 84: 533-561.

Fox, M.D. (1991) The natural vegetation of Ana Branch – Mildura 1: 250 000 map sheet (New South Wales. *Cunninghamia* 2: 443-494.

Howard, K.S.C., Eldridge, D.J. & Soliveres, S. (2012) Positive effects of shrubs on plant species diversity do not change along a gradient in grazing pressure in an arid shrubland. *Basic and Applied Ecology* 13: 159-168.

Hunter, J.T. (2015a) Seasonality of climate drives the number of tree hollows in eastern Australia: implications of a changing climate. *International Journal of Ecology* http://dx.doi.org/10.1155/2015/2F190637

Hunter, J.T. (2015b) Changes in allometric attributes and biomass of forests and woodlands across an altitudinal and rainfall gradient: what are the implications of increasing seasonality due to anthropogenic climate change? *International Journal of Ecology.* http://x.doi.org/10.1155/2015/2F208975

Hunter, J.T. (2013) Interactions between *Callitris* above ground biomass, species density and plant form in north eastern New South Wales. *Australian Journal of Botany* 6: 73-79.

Maestre, F.T., Bowker, M.A., Puche, M.D., Blen Hinojosa, M., Martinex, I., Garcia Palacios, P., Castillo, A.P., Soliveres, S., Luzuriaga, A.L., Sanchez, A.M., Carriera, J.A., Gallardo, A. & Escudera, A. (2009) Shrub encroachment can reverse desertification in semi-arid Mediterraenan grasslands. *Ecology Letters* 12: 930-941.

Morgan, H.R., Hunter, J.T., Gallard, G., Reid, N. & Flemming, P.J.S. (2016) Trophic cascades and dingoes in Australia: does the Yellowstone wolf-elk-willow model apply? *Food Webs*, *in press*.

Parsons, M. & Thoms, M.C. (2013) Patterns of vegetation community distribution in a large, semi-arid floodplain landscape. *Journal of Arid Environments* 88: 24-38.

Pickard, J. & Norris, E.H. (1994) The natural vegetation of north-western New South Wales: notes to accompany the 1:1 000 000 vegetation map sheet. *Cunninghamia* 3(3): 423-464.

Porteners, M.F., Ashby, E.M. & Benson, J.S. (1997) The natural vegetation of Pooncarie 1: 250 000 map. *Cunninghamia* 5: 139–231.

Preece, P.B. (1971) Contributions to the biology of mulga. II. Germination. *Australian Journal of Botany* 19: 39-49.

Sivertsen, D. (2009) *Native Vegetation Interim Type Standard.* (New South Wales Department of Environment, Climate Change and Water: Sydney).

Smith, A. (2013) Counting the cost: fire and reptiles. Are prescribed burning targets appropriate for reptile conservation? *Decision Point* **72**, 10–11.

Soliveres, S., Maestre, F.T., Bowker, M.A., Torices, R., Quero, J.L., Garcia-Gomez, M., Cabrera, O., Cea, A, Coaguila, D., Eldridge, D.J., Espinosa, C.I., Hemmings, F., Monerris, J.J., Tinghe, M., Delgado-Baquerizo, M., Escolar, C., Garcia-Palacios, P., Gozalo, B., Ochoa, V., Blones, J., Derak, M, Ghiloufi, W., Gutierrez, J.R., Hernandez, R.M. & Noumi, Z. (2014) Functional traits determine plant co-occurrence more than environment or evolutionary relatedness in global drylands. *Perspectives in Plant Ecology, Evolution and Systematics* 16: 164-173

Soliveres, S., Maestre, F., Eldridge, D.J., Delgado-Baquerizo, M., Luis Quero, J., Bowker, M.A. & Gallardo, A. (2014) Plant diversity and ecosystem multifunctionality peak at intermediate levels of woody cover in global drylands. *Global Ecology and Biogeography* 23: 1408-1416.

Specht, R.L. & Specht, A. (1999) *Australian Plant Communities: Dynamics of Structure, Growth and Biodiversity*. (Oxford University Press: Oxford).

Vickers, D., Hunter, J.T. & Hawes, W. (2014) Multiple species use of a water-filled tree hollow by vertebrates in dry woodland habitat of northern New South Wales. *Australian Zoologist* 37: 134-138.

Westhoff, V. & Maarel, V.D. (1978) The Braun–Blanquet approach. In *Classification of plant communities*. (Ed. RH Whittaker) pp. 617–726. (Junk: The Hague, The Netherlands)

Westoby, M. (1998) density-dependent germination and the role of seed leachate. *Australian Journal of Ecology* 23: 411-418.

Manuscript accepted 5 September 2016

Appendix 1: Checklist of species found within *Naree* and *Yantabulla* stations within the North Far Western Plains of New South Wales attributed to Association.

	A-01	A-02	A-03	A-04	A-05	A-06	A-07	A-08	A-09	A-10	A-11	A-12	A-13	A-14	A-15	A-16	Total
Fern & Fern Allies																	
Adiantaceae																	
Cheilanthes sieberi subsp. *sieberi*	1	1	1				1										4
Marsileaceae																	
Marsilea costulifera				1				1		1	1	1	1	1	1		8
Marsilea drummondii	1							1	1	1	1				1	1	7
Marsilea hirsuta											1						1
Gymnosperm		1			1		1								1		4
Cupressaceae																	
Callitris glaucophylla		1			1		1								1		4
Monocotyledon																	
Amaryllidaceae		1															1
Calostemma purpureum		1															1
Anthericaceae																	
Tricoryne elatior	1																1
Asphodelaceae																	
Bulbine alata	1						1			1							3
Cyperaceae																	
Cyperus bifax								1	1								2
Cyperus difformis	1			1					1								3
Cyperus gilesii		1						1	1								3
Cyperus iria									1	1		1			1		4
Cyperus squarrosus									1			1		1			3
Eleocharis acuta									1								1
Eleocharis pallens												1					1
Eleocharis plana								1									1
Eleocharis pusilla				1				1	1	1		1	1		1		7
Fimbristylis dichotoma	1	1	1	1	1		1			1			1		1	1	10
Schoenoplectus laevis															1		1

	A-01	A-02	A-03	A-04	A-05	A-06	A-07	A-08	A-09	A-10	A-11	A-12	A-13	A-14	A-15	A-16	Total
Juncaceae																	
Juncus aridicola								1	1	1				1			4
Phormiaceae																	
Dianella porracea	1														1		2
Poaceae																	
Amphipogon caricinus var. *caricinus*		1															1
Aristida blakei	1	1															2
Aristida calycina var. *praealta*	1																1
Aristida contorta	1	1	1				1										4
Aristida holathera var. *holathera*	1	1	1	1	1	1	1	1	1						1	1	11
Aristida jerichoensis var. *jerichoensis*	1		1												1		3
Aristida jerichoensis var. *subspinulifera*	1	1	1	1	1	1	1								1		8
Aristida latifolia	1	1															2
Aristida leptopoda	1	1					1										3
Aristida nitidula		1															1
Austrostipa nitida		1			1												2
Cenchrus caliculatus	1																1
Cenchrus ciliaris	1	1	1	1	1	1	1		1	1					1		10
Chloris truncata	1			1	1					1					1	1	6
Cymbopogon ambiguus		1	1		1												3
Cynodon dactylon				1				1	1			1		1			5
Dactyloctenium radulans	1	1	1	1	1	1		1	1	1	1		1	1	1		13
Dichanthium sericeum subsp. *humilis*	1	1			1	1									1		5
Digitaria ammophila	1																1
Digitaria brownii	1	1	1		1		1								1		6
Digitaria coenicola			1														1
Digitaria divaricatissima	1	1					1								1		4
Digitaria hystrichoides	1				1												2
Echinochloa inundata									1								1
Echinochloa turneriana		1		1					1	1							4
Elytrophorus spicatus				1						1					1		3
Enneapogon avenaceus	1	1	1	1	1	1	1		1	1	1				1		11

	A-01	A-02	A-03	A-04	A-05	A-06	A-07	A-08	A-09	A-10	A-11	A-12	A-13	A-14	A-15	A-16	Total
Enneapogon cylindricus	1	1			1										1		4
Enneapogon intermedius	1	1															2
Enneapogon nigricans	1				1			1		1					1		5
Enneapogon polyphyllus							1										1
Enteropogon acicularis	1	1	1	1	1	1	1	1	1	1					1	1	12
Eragrostis australasica								1	1	1			1	1			5
Eragrostis basedowii					1						1						2
Eragrostis brownii										1					1		2
Eragrostis cilianensis		1	1	1	1	1		1	1	1		1	1		1	1	12
Eragrostis dielsii			1	1	1			1	1	1	1	1	1		1	1	11
Eragrostis elongata		1								1							2
Eragrostis eriopoda	1	1	1	1	1	1	1								1		8
Eragrostis kennedyae	1	1	1				1								1		5
Eragrostis lacunaria	1	1		1	1	1		1	1	1	1	1	1		1	1	13
Eragrostis laniflora		1	1		1		1										4
Eragrostis leptocarpa	1		1														2
Eragrostis leptostachya	1																1
Eragrostis microcarpa			1												1		2
Eragrostis parviflora	1	1	1	1	1	1	1		1	1		1			1	1	12
Eragrostis setifolia	1		1												1		3
Eriachne aristidea							1										1
Eriachne helmsii	1	1			1		1								1		5
Eriachne mucronata		1															1
Eriochloa australiensis								1		1	1				1		4
Eriochloa pseudoacrotricha										1							1
Iseilema membranaceum										1							1
Monachather paradoxus	1	1	1				1				1				1		6
Panicum decompositum										1			1		1		3
Panicum effusum	1	1	1				1								1		5
Panicum laevinode	1							1	1	1		1	1		1	1	8
Panicum simile	1	1			1		1				1						5
Paspalidium constrictum	1	1	1		1	1									1		6

	A-01	A-02	A-03	A-04	A-05	A-06	A-07	A-08	A-09	A-10	A-11	A-12	A-13	A-14	A-15	A-16	Total
Paspalidium jubiflorum		1	1	1				1	1	1		1			1	1	9
Perotus rara	1	1	1				1										4
Poa fordeana			1														1
Sporobolus actinocladus	1	1		1	1				1	1		1			1		8
Sporobolus caroli	1		1	1				1	1	1	1	1	1	1	1	1	12
Sporobolus mitchellii	1	1		1	1			1	1	1	1	1	1	1	1	1	13
Themeda avenacea	1																1
Themeda triandra	1																1
Thyridolepis mitchelliana	1	1					1										3
Thyridolepis xerophila	1	1															2
Tragus australianus	1	1	1				1			1							5
Tripogon loliiformis	1	1	1		1										1		5
Triraphis mollis	1	1	1		1	1				1					1		7
Walwhalleya subxerophyllum										1					1		2
Pontederiaceae																	
Monochoria cyanea		1															1
Dicotyledon																	
Aizoaceae																	
Glinus lotoides								1	1	1	1		1	1			6
Mollugo cerviana		1						1									2
Tetragonia eremaea			1							1							2
Tetragonia tetragonioides										1							1
Trianthema triquetra			1		1	1		1	1	1					1		7
Zaleya galericulata	1																1
Amaranthaceae																	
Alternanthera angustifolia														1			1
Alternanthera denticulata								1	1	1	1	1			1		6
Alternanthera nodiflora	1							1	1	1	1	1		1	1	1	9
Amaranthus grandiflorus														1			1
Amaranthus macrocarpus								1	1						1		3
Ptilotus gaudichaudii var. *parviflorus*	1	1					1								1		4
Ptilotus leucocoma	1	1	1				1										4

	A-01	A-02	A-03	A-04	A-05	A-06	A-07	A-08	A-09	A-10	A-11	A-12	A-13	A-14	A-15	A-16	Total
Ptilotus polystachyus var. *polystachyus*	1	1	1				1								1		5
Ptilotus sessilifolius var. *sessilifolius*			1				1										2
Apiaceae																	
Ammi majus	1	1															2
Trachymene glaucifolia	1																1
Trachymene ochracea	1																1
Apocynaceae							1										1
Alstonia constricta							1										1
Asclepiadaceae																	
Marsdenia viridiflora			1														1
Asteraceae																	
Angianthus brachypappus					1												1
Brachyscome ciliaris var. *lanuginosa*			1							1						1	3
Brachyscome melanocarpa		1			1			1		1					1		5
Calocephalus sonderi							1										1
Calotis cuneifolia		1					1					1					3
Calotis erinacea							1										1
Calotis hispidula	1		1							1							3
Calotis inermis	1																1
Calotis lappulacea	1	1					1										3
Centaurea calcitrapa				1													1
Centipeda crateriformis subsp. *compacta*	1								1	1			1	1	1		6
Centipeda cunninghamii				1					1					1			3
Centipeda minima var. *minima*	1							1	1	1	1			1	1		7
Centipeda thespidioides	1	1			1	1		1	1	1	1	1	1	1	1	1	13
Epaltes australis									1		1			1			3
Glossocardia bidens	1														1		2
Gnephosis arachnoidea							1										1
Gnephosis eriocarpa		1															1
Leiocarpa semicalva subsp. *semicalva*	1							1		1							3
Leptorhynchos baileyi		1			1											1	3
Minuria integerrima											1						1

	A-01	A-02	A-03	A-04	A-05	A-06	A-07	A-08	A-09	A-10	A-11	A-12	A-13	A-14	A-15	A-16	Total
Olearia pimeleoides			1		1	1	1			1							5
Pluchea dentex								1	1		1						3
Pluchea tetranthera								1	1	1					1		4
Pseudognaphalium luteoalbum									1								1
Pterocaulon sphacelatum			1		1			1	1	1				1	1	1	8
Pycnosorus thompsonianus	1																1
Senecio magnificus									1								1
Senecio runcinifolius	1				1									1			3
Sigesbeckia australiensis	1	1															2
Sonchus oleraceus										1							1
Streptoglossa adscendens								1	1								2
Streptoglossa liatroides	1																1
Stuartina muelleri	1										1						2
Vittadinia cuneata var. *cuneata*	1	1														1	3
Vittadinia dissecta var. *hirta*					1												1
Vittadinia pterochaeta	1							1	1								3
Vittadinia sulcata			1					1									2
Xanthium occidentale										1							1
Boraginaceae																	
Heliotropium supinum									1					1			2
Omphalolappula concava	1	1	1												1		4
Brassicaceae																	
Lepidium bonariense										1							1
Lepidium sagittulatum	1																1
Sisymbrium erysimoides		1							1								2
Campanulaceae																	
Wahlenbergia communis										1	1						2
Wahlenbergia gracilis	1														1		2
Wahlenbergia tumidifructa	1		1		1												3
Capparaceae																	
Capparis mitchellii						1			1								2
Caryophyllaceae		1								1			1		1		4

	A-01	A-02	A-03	A-04	A-05	A-06	A-07	A-08	A-09	A-10	A-11	A-12	A-13	A-14	A-15	A-16	Total
Gypsophyla tubulosa		1															1
Polycarpaea corymbosa var. *minor*													1				1
Silene gallica var. *gallica*										1					1		2
Casuarinaceae																	
Casuarina pauper			1		1	1	1										4
Chenopodiaceae																	
Atriplex angulata					1				1	1	1		1				5
Atriplex eardleyae		1	1	1	1	1		1	1	1			1		1	1	11
Atriplex elachophylla									1	1							2
Atriplex holocarpa			1	1				1		1							4
Atriplex leptocarpa								1	1								2
Atriplex limbata			1		1	1			1	1							5
Atriplex nessorhina					1												1
Atriplex pseudocampanulata				1						1			1				3
Atriplex stipitata				1	1	1			1	1			1				6
Atriplex suberecta									1								1
Atriplex turbinata					1												1
Chenopodium auricomum								1	1						1		3
Chenopodium cristatum			1			1				1	1						4
Chenopodium desertorum subsp. *desertorum*	1				1	1	1								1		5
Chenopodium melanocarpum	1	1				1			1	1	1	1		1	1		9
Chenopodium nitrariaceum										1							1
Dissocarpus paradoxus			1		1	1	1										4
Dysphania kalpari															1		1
Dysphania littoralis										1	1						2
Dysphania rhadinostachya subsp. *inflata*	1	1	1														3
Einadia hastata						1				1							2
Einadia nutans subsp. *nutans*			1	1	1	1			1	1						1	7
Einadia trigonos	1		1														2
Enchylaena tomentosa			1		1	1	1	1	1	1	1				1		9
Maireana brevifolia	1		1	1		1			1	1	1		1				8
Maireana decalvans			1		1												2

	A-01	A-02	A-03	A-04	A-05	A-06	A-07	A-08	A-09	A-10	A-11	A-12	A-13	A-14	A-15	A-16	Total
Maireana triptera			1														1
Maireana villosa	1	1	1	1	1			1									6
Salsola australis			1		1	1			1	1							5
Sclerolaena bicornis var. *bicornis*						1											1
Sclerolaena bicornis var. *horrida*			1					1		1							3
Sclerolaena birchii	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1	15
Sclerolaena convexula	1	1	1		1		1					1			1		7
Sclerolaena decurrens			1		1	1		1	1	1	1		1		1		9
Sclerolaena diacantha	1	1	1		1	1	1			1	1						8
Sclerolaena divaricata										1							1
Sclerolaena lanicuspis			1		1												2
Sclerolaena muricata var. *muricata*								1									1
Sclerolaena muricata var. *semiglabra*			1	1			1	1	1	1		1	1	1			9
Sclerolaena tricuspis		1		1	1	1				1							5
Tecticornia indica subsp. *leiostachya*													1				1
Convolvulaceae																	
Convolvulus clementii	1									1	1				1		4
Convolvulus remotus	1	1								1	1					1	5
Evolvulus alsinoides var. *villosicalyx*	1	1			1		1				1				1		6
Crassulaceae																	
Crassula sieberiana	1																1
Cucurbitaceae																	
Citrullus lanatus									1					1	1		3
Cucumis myriocarpus			1							1				1	1		4
Elatinaceae																	
Bergia trimera											1						1
Euphorbiaceae																	
Chamaesyce dallachyana								1									1
Chamaesyce drummondii	1	1	1		1		1	1	1	1	1	1			1	1	12
Phyllanthus lacunarius									1								1
Phyllanthus virgatus					1			1							1	1	4
Sauropus trachyspermus								1								1	2

	A-01	A-02	A-03	A-04	A-05	A-06	A-07	A-08	A-09	A-10	A-11	A-12	A-13	A-14	A-15	A-16	Total
Fabaceae																	
Acacia aneura	1	1	1	1	1	1	1		1			1			1		10
Acacia brachystachya	1	1					1										3
Acacia excelsa subsp. *angusta*	1	1	1		1	1	1	1	1						1		9
Acacia homalophylla					1												1
Acacia oswaldii			1		1												2
Acacia ramulosa		1															1
Acacia stenophylla		1						1	1	1				1	1		6
Acacia tetragonophylla		1		1	1					1							4
Acacia victoriae subsp. *victoriae*	1	1	1	1	1	1	1	1	1	1	1	1			1	1	14
Cullen cinereum									1								1
Glycine canescens	1																1
Lotus cruentus										1							1
Medicago polymorpha								1	1	1							3
Medicago truncatula								1									1
Rhynchosia minima										1							1
Senna artemisioides subsp. *x coriacea*	1				1			1									3
Senna artemisioides subsp. *filifolia*	1	1	1	1	1		1		1						1		8
Senna artemisioides subsp. *x sturtii*			1		1		1										3
Senna artemisioides subsp. *zygophylla*	1	1	1		1	1	1	1		1		1			1		10
Swainsona affinis	1																1
Tephrosia sphaerospora							1	1									2
Frankeniaceae																	
Frankenia uncinata								1		1	1		1	1			5
Geraniaceae																	
Erodium crinitum	1		1		1						1				1		5
Goodeniaceae																	
Goodenia cycloptera	1	1															2
Goodenia glabra	1	1	1														3
Goodenia glauca									1								1
Goodenia lunata	1																1
Scaevola spinescens	1																1

	A-01	A-02	A-03	A-04	A-05	A-06	A-07	A-08	A-09	A-10	A-11	A-12	A-13	A-14	A-15	A-16	Total
Velleia arguta	1																1
Velleia paradoxa		1					1										2
Haloragaceae																	
Haloragis glauca forma *glauca*								1	1						1		3
Myriophyllum verrucosum								1									1
Lamiaceae																	
Teucrium racemosum				1				1	1	1	1	1			1	1	8
Linaceae																	
Linum marginale										1						1	2
Lobeliaceae																	
Pratia darlingensis	1									1		1			1		4
Loranthaceae																	
Amyema cambagei	1																1
Amyema lucasii							1										1
Amyema maidenii subsp. *maidenii*		1					1										2
Lysiana exocarpi					1		1										2
Lysiana subfalcata									1								1
Lythraceae																	
Ammannia multiflora									1					1			2
Malvaceae																	
Abutilon leucopetalum									1								1
Abutilon malvifolium															1		1
Abutilon otocarpum	1	1	1	1	1	1	1	1	1		1				1		11
Abutilon oxycarpum	1	1	1								1	1			1		6
Hibiscus sturtii var. *grandiflorus*	1	1					1										3
Hibiscus sturtii var. *sturtii*		1															1
Hibiscus trionum								1	1	1							3
Malva parviflora										1							1
Malvastrum americanum	1			1				1	1	1	1				1	1	8
Malvastrum coromandelianum	1																1
Sida ammophila					1												1
Sida corrugata										1							1

	A-01	A-02	A-03	A-04	A-05	A-06	A-07	A-08	A-09	A-10	A-11	A-12	A-13	A-14	A-15	A-16	Total
Sida cunninghamii		1			1	1											3
Sida fibulifera	1		1		1										1		4
Sida filiformis	1	1	1		1	1	1	1		1					1		9
Sida goniocarpa		1		1	1			1	1	1	1	1				1	9
Sida intricata				1	1												2
Sida platycalyx		1					1			1							3
Sida trichopoda	1	1	1		1		1	1			1				1		8
Meliaceae																	
Owenia acidula					1												1
Myrtaceae																	
Corymbia tumescens	1	1			1		1								1		5
Eucalyptus coolabah	1				1			1	1	1	1			1	1		8
Eucalyptus largiflorens					1			1	1	1				1	1	1	7
Eucalyptus melanophloia		1															1
Eucalyptus ochrophloia		1			1			1	1								4
Eucalyptus populnea subsp. *bimbil*	1	1	1		1	1				1	1	1	1		1	1	11
Thryptomene hexandra	1	1															2
Nyctaginaceae																	
Boerhavia coccinea		1	1		1	1	1	1								1	7
Boerhavia dominii										1							1
Boerhavia repleta				1				1	1	1		1			1		6
Oleaceae																	
Jasminum lineare			1														1
Onagraceae																	
Ludwigia peploides subsp. *montevidensis*								1	1					1			3
Oxalidaceae																	
Oxalis chnoodes															1		1
Oxalis exilis			1														1
Oxalis perennans	1									1					1		3
Papaveraceae																	
Argemone ochroleuca subsp. *ochroleuca*										1				1			2

	A-01	A-02	A-03	A-04	A-05	A-06	A-07	A-08	A-09	A-10	A-11	A-12	A-13	A-14	A-15	A-16	Total
Plantaginaceae																	
Plantago turrifera	1																1
Polygonaceae																	
Duma florulenta		1		1				1	1	1			1	1	1	1	9
Persicaria lapathifolia									1								1
Portulacaceae																	
Calandrinia eremaea	1		1												1	1	4
Portulaca oleracea	1		1		1			1	1	1	1		1		1	1	10
Proteaceae																	
Grevillea striata	1	1	1	1	1		1	1							1		8
Hakea eryeana	1	1															2
Hakea ivoryi	1	1	1		1		1		1			1			1		8
Hakea leucoptera subsp. *leucoptera*			1		1			1							1	1	5
Hakea tephrosperma			1		1			1	1						1		5
Ranunculaceae																	
Ranunculus sessiliflorus var. *sessiliflorus*										1							1
Rhamnaceae																	
Ventilago viminalis			1		1		1										3
Rosaceae																	
Potentilla supina									1								1
Rubiaceae																	
Dentella minutissima											1						1
Psydrax latifolium		1															1
Rutaceae																	
Flindersia maculosa			1		1	1	1										4
Santalaceae																	
Santalum acuminatum			1	1	1	1									1		5
Sapindaceae																	
Alectryon oleifolius subsp. *canescens*			1		1	1	1										4
Atalaya hemiglauca	1		1	1	1		1		1								6
Dodonaea boroniifolia		1					1										2

	A-01	A-02	A-03	A-04	A-05	A-06	A-07	A-08	A-09	A-10	A-11	A-12	A-13	A-14	A-15	A-16	Total
Dodonaea viscosa subsp. *angustifolia*	1	1	1	1	1	1	1		1	1		1		1	1	1	13
Dodonaea viscosa subsp. *angustissima*			1				1										2
Scrophulariaceae																	
Eremophila bignoniiflora		1		1				1	1								4
Eremophila bowmanii subsp. *latifolia*		1															1
Eremophila deserti	1	1	1	1	1	1	1	1	1	1	1				1		12
Eremophila gilesii	1	1	1				1		1						1		6
Eremophila glabra	1	1	1		1	1	1	1	1	1					1		10
Eremophila goodwinii	1	1	1												1		4
Eremophila latrobei		1															1
Eremophila longifolia	1	1	1		1		1			1		1			1		8
Eremophila mitchellii	1		1		1	1									1		5
Eremophila sturtii	1	1	1	1	1	1	1	1	1	1	1			1	1	1	14
Glossostigma diandrum										1							1
Myoporum montanum		1	1	1	1	1		1	1	1	1		1	1	1	1	13
Stemodia florulenta															1		1
Stemodia glabella									1	1	1			1	1	1	6
Solanaceae																	
Lycium ferocissimum						1											1
Nicotiana simulans	1														1		2
Solanum cinereum	1														1		2
Solanum cleistogamum	1	1		1	1	1	1		1			1			1		9
Solanum coactiliferum	1		1							1					1		4
Solanum ellipticum	1	1													1		3
Solanum esuriale	1		1	1	1		1	1	1	1		1			1	1	11
Solanum ferocissimum	1	1					1								1		4
Solanum lacunarium								1	1								2
Solanum parvifolium	1	1													1		3
Solanum sturtianum	1																1
Sterculiaceae																	
Brachychiton populneus subsp. *populneus*		1															1
Brachychiton populneus subsp. *trilobus*	1																1

	A-01	A-02	A-03	A-04	A-05	A-06	A-07	A-08	A-09	A-10	A-11	A-12	A-13	A-14	A-15	A-16	Total
Thymelaeaceae																	
Pimelea microcephala subsp. *microcephala*			1		1	1				1							4
Pimelea trichostachya	1	1	1	1			1			1					1		7
Verbenaceae															1		1
Verbena gaudichaudii															1		1
Zygophyllaceae																	
Tribulus terrestris			1														1
Zygophyllum iodocarpum			1														1

Date of Publication:
December 2016

Cunninghamia

A journal of plant ecology for eastern Australia

The Royal
Botanic Garden
Sydney

ISSN 0727-9620 (print) • ISSN 2200-405X (Online)

Distinctive corticolous myxomycete assemblages of tropical, temperate and arid regions of Australia

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Abstract: Myxomycetes (plasmodial slime moulds) information is provided for three new moist-culture bark surveys in Australia. These are in the Northern Territory, Queensland and southeast New South Wales. The Northern Territory and Queensland surveys are in the form of long traverses from near the coast to the drier inland. Both of these surveys show a similar result - a tropical assemblage in the band of higher rainfall bordering the coast, and a northern dry assemblage in the inland area. The boundary is at about 650 mm average annual rainfall. At the boundary there is a transition zone, 300-400 km wide, within which both assemblages occur. These surveys, a new survey in SE New South Wales, and an existing survey in NW New South Wales, form an intermittent traverse across Australia from Darwin via Alice Springs to Canberra. The traverse has four distinct species assemblages: tropical, northern dry, southern dry and temperate. The three myxomycete assemblage boundaries correspond with the major climatic subdivisions of Australia, and the more important Australian phytogeographic region boundaries. Because the boundaries of the myxomycete assemblages, where known, correspond with those of the climatic and phytogeographic regions, the extent of the corticolous myxomycete assemblages over much of Australia can be inferred. Two of the Australian myxomycete assemblages are very similar to Northern Hemisphere assemblages of areas of similar climate.

***Cunninghamia* (2016) 16: 101–114**
doi: 10.7751/cunninghamia.2016.16.009

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Introduction

Myxomycetes (plasmodial slime moulds) are a small group of fungus-like organisms with a two-stage life cycle; a single nucleate phase (amoeboid or flagellated), and a multinucleate (single cell) phase starting as a plasmodium and ending as a fruiting body (containing spores) generally 0.5-2 mm high. Identification is based on the dried fruiting body.

Pre 1995 records of Australian myxomycetes are listed by Mitchell (1995). Subsequent papers on myxomycetes on wood, bark, and litter are reported by Ing & Spooner (1994), McHugh et al. (2003), Black et al. (2004), Jordan et al. (2006), Rosing et al. (2007), Davison et al. (2008) McHugh et al. (2009), Knight and Brims (2010), Lloyd (2014), Wellman (2015) and Davison et al. (in press). Myxomycetes on liana material are reported by Wrigley de Basanta et al. (2008), and those associated with snowbanks by Stephenson and Shadwick (2009). Most of these studies were carried out within the wide band of higher rainfall along the Australian coastline. This has a greater range of ecological habitats than the drier area inland.

Most previous papers on Australian myxomycetes are aimed at finding which myxomycetes species are found in Australia generally, and in each state and territory. Hence these papers mainly report the relatively rare species, or those from new areas, and they do not necessarily report the common species found. This paper, and Wellman (2015), concentrate on finding the areal extent of the relatively common species, identifying areas with a common species assemblage.

This paper describes the change in species assemblage along a composite traverse across Australia. The traverse can be divided into sections, each with a distinct species assemblage. The location of changes in species assemblages can be compared between that of the myxomycetes and that of the flowering and non-flowering plants, testing whether the phytogeographic regions also apply to more primitive organisms. Using the phytogeographic regions and the climatic information, the traverse information could then be used to infer a likely distribution of myxomycete assemblages throughout much of Australia. Australia is a good location to study myxomycete assemblages because it has a generally low relief, and the climate changes relatively gradually across the continent.

Materials and methods

Sample collection

The field collecting in Northern Territory (NT) and Queensland (Qld) was carried out during late June 2015 - in winter. The weather is then generally dry so the myxomycetes are dormant, and the temperature is generally cooler, which is more comfortable for field work. Traverses were selected to have the greatest range in average rainfall, and to be along sealed roads. Two traverses were collected (Fig. 1). In the Northern Territory a traverse was collected from Darwin to Alice Springs along the main road, a road distance of 1500 km. In Queensland a traverse was conducted from near Cairns to Winton in central Queensland via Ravenshoe and Charters Towers, a road distance of 940 km. In both areas the rainfall of the previous rainy season (months of November to April) had been only slightly less than average. Samples were collected on both the outward journey and the return journey. The return journey samples filled gaps in sample spacing and increased the range of bark type. The traverses were shortened slightly from those planned because of unseasonal minor rainfall immediately before the sampling near Darwin, near Alice Springs and west of Cairns. Samples were not collected in these areas of recent rainfall. Along most of the NT traverse the roadside had been lightly burnt over the last few years in order to control wild fires. Litter, grass and shrubs were burnt and the dead bark of the living trees being singed black in places. Bark was only collected from tree trunk portions which had little or no charcoal. The singeing does not appear to affect the myxomycetes in the collected samples. Appendix 1 lists, for each sample, the location and the name of the tree sampled.

The other results reported here are for an area centred on the city of Canberra. It includes part of south-eastern New South Wales (SE NSW), and all of the Australian Capital Territory (ACT) (Fig. 1). These samples were not collected as a traverse, but were spot samples collected for a range of local environments varying in altitude and rainfall. The samples were collected between November 2012 and September 2013 from a large range of Australian and exotic trees. Appendix 2 lists, for each sample, the location and the name of the tree sampled.

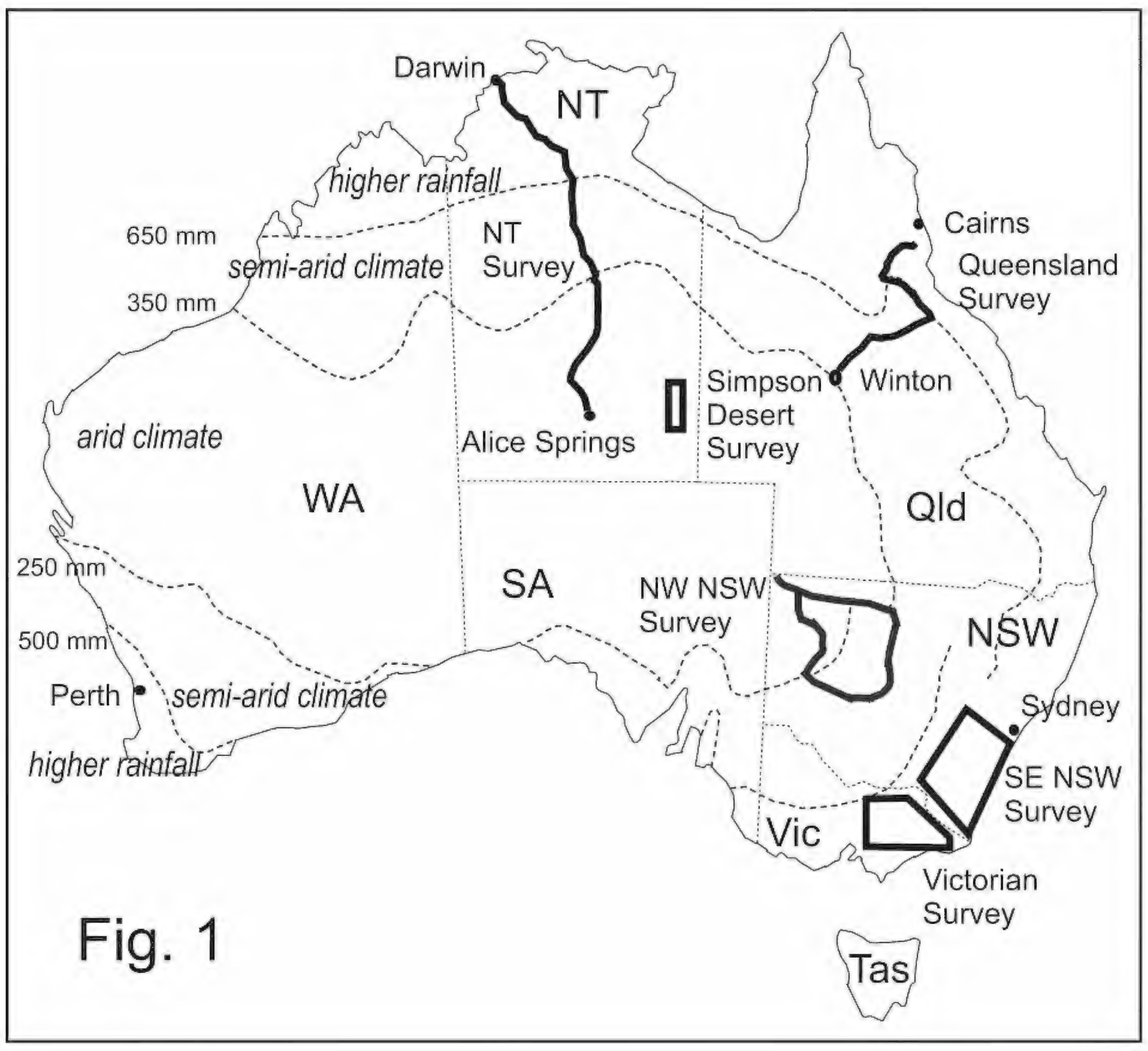

Fig. 1. Location of myxomycete surveys, and distribution of arid and semi-arid climate in Australia. Surveys: NT, Qld, SE NSW (present study), Simpson Desert (Davison et al., 2008), Victorian (Rosing et al., 2007), NW NSW (Wellman 2015). The climatic regions are bounded by mean annual rainfall contours: rainfall values are given in mm.

For all surveys the samples were collected in paper bags. A single mixed sample was collected, consisting of small pieces of dead bark from living trees, about 1.5 m above ground level, from all sides of the tree trunk, and from 1-4 trees. Tree bark samples were preferably taken within groves of trees so that, with greater shading, the drying of the bark would be slower. In each area the samples were selected to cover the range of tree bark types. The samples were stored in a cool, dry place until processed.

Moist chamber culture

The moist culture method used was that described by Stephenson and Stempen (1994). Petri dishes 90 mm in diameter were used, with a single layer of filter paper placed on the bottom. Five replicate Petri dishes were prepared for each sample. The individual pieces of bark comprising the sample were cut or broken up into postage stamp sized fragments before they were put in a Petri dish on top of the filter paper with the weathered surface of the bark uppermost. Fragments from the same piece of bark were divided among five Petri dishes so that, with variations in moisture history among the Petri dishes, there was a greater likelihood of obtaining a fruiting body. Petri dishes were half filled with distilled water, covered, left for 24 hours, and then the excess water was poured off. Dishes were kept covered, but not sealed, at about 22°C with only reflected daylight. Each week dishes were inspected with a stereomicroscope at 7x and greater magnification, and the mature fruiting bodies removed, dried, and glued to small piece of cardboard. At each inspection a small amount of water was added to keep the samples damp. The NT and Qld samples were kept reasonably moist for a long period. Thinner, low-density samples need about 6 drops of water per week, while thicker, more-dense samples need about 12 drops per week (44 drops = 5 g). For each Petri dish there was between 6 and 10 inspections. These inspections were broken by one drying out and re-wetting event, so there were two periods of complete drying. The SE NSW samples had a greater range of moistness, spending more time both too dry and too wet. This may have contributed to the low number of species and fruiting bodies from these samples.

Species identification

Temporary microscope slides were made by soaking the material in alcohol and then 5% KOH solution. Semi-permanent microscope slide mounts of many species were made to study the stalk, peridium, capillitium, and inflated spores by soaking the fruiting body sequentially in alcohol, in 5% KOH solution, in water, and then in 'Brite' mountant (a USA furniture polish used for liverwort slides), and covering with a cover slip. After each soaking the excess fluid was removed using narrow strips of filter paper. Semi-permanent mounts of members of the Stemonitaceae were made by blowing spores off the fruiting body, placing the fruiting body horizontally in the air space of a cavity slide (gluing is unnecessary), and covering the cavity with a cover slip fastened at the edge with 'Scotch' tape.

Identification of the dried fruiting bodies of myxomycetes was mainly carried out using Nannenga-Bremekamp (1991), Ing (1999), Stephenson (2003), Poulain et al. (2011), and the website Discover Life (2015).

Table 1 lists the species identified from the three new surveys. Following the species name is a list of each locality where the species is found and the number of fruiting bodies collected at that locality. Identifications considered doubtful are marked 'cf.'

One of the objects of the paper was to provide quantitative information on the abundance of species, but this proved difficult for some species groups. The identification of *Echinostelium* was found to be very time consuming so some fruiting bodies are listed as *Echinostelium* 'short', where they were not *Echinostelium minutum, or E. arboreum.* For some *Physarum* identification was not possible. The fruiting bodies were few in number or defective. These are reported as *Physarum* 'various species'.

Comatricha elegans and *C. ellae* are an important part of the species assemblage, but their identification was difficult. With the spores present the species have a similar appearance at 7x-50x magnification. Both species are present in some samples so the most reliable identifications for fruiting body with a height greater than 0.6 mm, result from putting 4-6 blown fruiting bodies in one cavity slide, and making an identification of each fruiting body at 100x magnification. Separation of the species is easy for large sporangium, and questionable for smaller sporangium. Standard texts (Ing, 1999, Poulain & others, 2011; Nannenga-Bremekamp, 1991) give a minimum height of 0.5 mm for *C. elegans* and 0.6 mm for *C. ellae*. Fruiting bodies similar to *ellae* and *elegans*, but smaller (0.3-0.6 mm high), are found in at least 16 sites. These fruiting bodies have intertwined fibres at the base of the stalk, and spores about 10 µm in diameter with small ornamentation. The capillitium is simple, flexuous, and the capillitium free ends generally are not of reduced diameter. These fruiting bodies are interpreted as small *ellae* and *elegans*. Over most of the Australian areas discussed below both *C. ellae* and *C. elegans* are found. The main separation used in this paper is the presence or absence of capillitium branches below the top of the columella. If some small branches are allowed in *C. elegans* then most of the material would be *C. elegans*.

The fruiting body abundance recorded for each sample is the only information we have to determine the abundance of that species on the substrate in natural conditions. A species like *Cribraria minutissima,* which locally has many occurrences and high abundance, must be a very important part of that species assemblage in the area in which it occurs. A species like *Comatricha vineatilis*, which was found in only two samples, and with only 6-7 fruiting bodies, is likely to be a very minor part of the species assemblage. A species such as *Physarum album*, which was found at only one locality, but with 165 fruiting body, may be locally very common, and a larger part of the assemblage than the one sample occurrence implies. The abundance numbers are of course biased by the difficulty of seeing or identifying some fruiting bodies.

The two unusual species found are described below.

Oligonema? sp A

The fruiting body is a stalked sporangium, clustered, and 0.7-1.1 mm tall. The clusters are 2-5 sporotheca, the cluster

0.4-0.8 mm high and 0.6-1.2 mm wide. Each sporotheca is globose, but irregular from pressure, and about 0.4 mm in diameter. They have a top and sides which is ochraceous with darker irregular areas, and a base the colour and texture of the stalk. Stalk is 0.3-0.4 mm tall and 0.14-0.4 mm diameter, irregular and lumpy near the base, plicate near the top, dark brown and shiny. For some bodies the hypothallus is extensive and buttressed to the stalk. The capillitium is a brownish yellow, averages about 10 µm in diameter, and a length of 10-90 µm. It is are very irregular in diameter and direction, with many constrictions and some branching. It has faint spirals, and prominent, isolated, blunt spines that are 1 um in diameter and 1-5 µm long, often occurring at the ends of the capillitium. Spores are slightly dark ochraceous in mass, very pale yellow in transmitted light, covered uniformly with spines, not quite spherical, and 11 µm in diameter. This species capillitium is shorter, but similar to that of *Oligonema schweinitzii*.

Badhamia sp A. The fruiting body is generally a plasmodiocarp, 0.8 x 0.8 to 2.3 x 0.8 mm area, and 0.2 or 0.4 mm thick. One locality has sessile or short stalked bodies 0.2-0.3 mm high and 0.2-0.4 mm diameter. Hypothalus is extensive and dark brown. The peridium is thin and translucent, with iridescent reflections. Its surface shows spore balls, irregular lumps, and folds as from peridium stretching. The thinner fruiting bodies have no peridium lime. The thicker bodies have the upper half covered by round to elongate, thick, white to slightly yellow, blobs of lime 20-40 µm in width. The capillitium in thicker bodies is thick, continuous, and badhamioid. Spores black in mass, dark violet-brown by transmitted light, in firm clusters of 6-10. They are generally spherical, uniformly warted, and about 12 µm in diameter.

Of some interest is the average number of species per tree bark sample. The work that I have done in Australia is based on filling 5 Petri dishes with bark from one tree species at one site and calling it a sample. For the traverses reported above, the Darwin to Alice traverse gave an average of 6.0 records per sample, the Cairns to Winton traverse gave an average of 6.7 records per sample, and the SE NSW samples gave an average of 3.8 records per sample. In NW NSW Wellman (2015) reports an average of 6.6 identified species per sample. In comparison, in Colorado, Novozhilov et al. (2003) worked with one Petri dish per site, and obtained an average of 3.3 species per site.

Table 1. The species of myxomycete found in the three surveys reported in this paper. For each species there is a list of number pairs, the first number is that of the sample, and the second is the number of fruiting bodies found. Samples 768A to 887 are the SE New South Wales survey, 1001- 1055 the Northern Territory traverse, samples 1056 to 1087 the Queensland traverse.

Arcyria cinerea (Bull.) Pers. (769, 1; 770, 3; 771, 17; 774, 15; 777B, 42, 778B, 20; 826B, 11; 830B, 3; 1005, 5; 1007, 2; 1013, 2; 1017, 91; 1018, 41; 1019, 1; 1022, 7; 1027, 23; 1031, 19; 1036, 19; 1046,25; 1048,2; 1054, 5; 1055, 17; 1057,3; 1059, 8; 1062, 10; 1064, 55; 1068, 16; 1072, 9; 1073, 34; 1078, 35; 1079, 57; 1083, 67; 1084, 85).

Arcyria globosa Schwein (1001, 8).

Arcyria margino-undulata Nann, -Bremek & Y. Yamam (1008, 7).

Arcyria pomiformis (Leers) Rostaf (768B, 1; 817G, 1; 835, 32)

Arcyria cf. riparia L. G. Krieglst (827A, 2; 887, 21)

Arcyria sp. H (834, 8; 1013, 8; 1035, 86; 1039, 6; 1051, 60; 1057, 16; 1060, 147; 1087, 1; 1089, 5). (See McHugh et al., 2003; Davison et al., 2008; Wellman, 2015)

Badhamia affinis Rostaf (771, 10; 1016, 40; 1019, 32; 1022, 150; 1027, 60).

Badhamia sp A (1027, 1; 1046, 1; 1076, 430; 1079, 10; 1084, 13). See text for description.

Badhamia macrocarpa (Ces) Rostaf (845, 12)

Badhamia versicolor Lister (775B, 42).

Badhamiopsis ainoae (Yamash) T. E Brooks & H. W Keller (845, 12; 1011, 20; 1032 26; 1034, 2; 1045, 19; 1061, 9; 1064, 380; 1080, 2).

Calomyxa metallica (Berk) Nieuwl (817D, 1; 830A, 14; 830B, 2; 844, 5; 858A, 4; 858C, 20; 858D, 43; 858E, 17; 858F, 4; 858G, 3; 858H, 1; 1011, 28; 1028, 1; 1033, 49; 1034, 3; 1038, 27; 1039, 1; 1040, 7; 1042, 4; 1063, 16; 1064, 1; 1065, 54; 1072, 1; 1080, 21).

Clastoderma debaryanum A. Blytt (809B, 600; 1037, 7; 1060, 6; 1061, 34; 1066, 1; 1073, 11; 1086, 1).

Clastoderma pachypus Nann, -Bremek (1005, 4; 1086, 70; 1087, 50; 1089, 50).

Comatricha anomala Rammeloo (830B, 19)

Comatricha elegans (Racib) G. Lister (769, 10; 773, 2; 809A, 2; 1005, 31; 1006, 42; 1007, 36; 1008, 8; 1015, 4; 1016, 50; 1031, 115; 1035, 105; 1048, 1; 1051, 10; 1054, 3; 1056, 30; 1057, 22; 1058, 128; 1059, 55; 1061, 1; 1062, 110; 1063, 15; 1066, 9; 1067, 38; 1069, 17; 1072,2; 1076,12; 1077, 2; 1079, 21; 1083, 15; 1089,72).

Comatricha ellae Härk (768B, 7; 771, 6; 772A, 50; 777B, 31; 809B, 1; 817C, 5; 817G, 1; 834, 20; 835, 22; 1001, 70; 1015, 5; 1018, 10; 1030, 5; 1032, 1; 1033, 5; 1034, 1; 1035, 91; 1037, 49; 1038, 6; 1039, 2; 1040, 10; 1042, 20; 1055, 19; 1056, 30; 1057, 22; 1060, 200; 1065, 1; 1067, 31; 1069, 17; 1083, 15; 1085, 6; 1086, 71; 1087, 118).

Comatricha laxa Rostaf (778B, 6; 1013, 3; 1056, 19; 1057, 200; 1071, 10).

Comatricha nigra (Pers ex J. F Gmel) J. Schröt (827A, 10).

Comatricha cf. *pulchella* (C. Bab) Rostaf (1006, 1).

Comatricha vineatilis Nann, -Bremek (769, 7; 1035, 6; 1083, 7).

Cribraria confusa Nann, -Bremek & Y. Yamam (768B, 180; 777B, 80; 778B, 50; 809A, 40; 809B, 1; 810, 100; 826A, 40; 826E, 114; 827A, 6; 1002, 4; 1005, 49; 1007, 12; 1013, 2; 1017, 10; 1018, 2; 1048, 6; 1052, 110; 1054, 43; 1056, 14; 1057, 26; 1058, 20; 1062, 42; 1089, 3).

Cribraria microcarpa (Schrad) Pers (826B, 80; 826E, 1)

Cribraria minutissima Schwein (772C, 1200; 777B, 1000; 778B, 85; 809A 20; 809B, 80; 1005, 186; 1007, 174; 1008, 184; 1013, 20; 1015, 41; 1016, 130; 1017, 350; 1018, 220; 1048, 27; 1051, 100; 1054, 300; 1055, 700; 1056, 220; 1057, 3; 1058, 70; 1059, 230; 1060, 100; 1062, 240; 1063, 100; 1067, 850; 1069, 20; 1083, 68; 1086,30; 1087, 650; 1089, 280).

Cribraria cf. *stellifera* Nowotny, and H. Neubert (778B, 32; 809B, 10)

Cribraria cf. *oregana* H. C. Gilbert (1008, 21).

Cribraria violacea Rex (770, 4; 828A, 70; 858C, 3; 858H, 5; 1010, 13; 1011, 3; 1019, 31; 1020, 38; 1046, 232; 1049, 19; 1061, 15; 1064, 146; 1072, 2; 1084, 31; 1085, 60).

Cribraria sp A (1010, 285) (also reported in Wellman, 2015).

Didymium clavus (Alb & Schwein) Rabenh (1010, 44; 1046, 6; 1061, 5).

Didymium dubium Rostaf (1027, 07; 1038, 3; 1040, 11; 1044, 2; 1063, 11; 1070 cf., 2; 1075, 67; 1080, 9).

Echinostelium apitectum K. D. Whitney (1028, 10; 1048, 70; 1049, 100; 1057, 50; 1070, 50; 1074, 50; 1076, 20; 1078, 200).

Echinostelium arboreum H. W. Keller & T. E Brooks (858C, 7; 1010, 50; 1064, 11; 1071, 200; 1077, 30).

Echinostelium colliculosum K. D. Whitney & H. W Keller (1024, 10).

Echinostelium minutum de Bary (774, 50; 778B, 25; 817B, 5; 817C, 4; 817E, 100; 817F, 170; 817G, 10; 826B, 20; 830B, 12; 835, 30; 858A, 100; 858B, 20; 1008, 20; 1013, 20; 1015, 10; 1016, 4; 1040, 200; 1048, 1; 1051, 120; 1054, 400; 1056, 100; 1057, 25; 1063, 50; 1086, 10; 1087, 5).

Echinostelium sp. (not *minutum* or *arboretum*) (771, 10; 809B, 10; 817B, 5; 817G, 10; 1002, 10; 1005, 53; 1006, 42; 1008, 20; 1011, 30; 1032, 1; 1038, 200; 1051, 30; 1055, 10; 1056, 25; 1057, 93; 1062, 20; 1067, 1; 1069, 3; 1073, 1000; 1079, 200; 1084, 40; 1089, 40).

Enerthenema papillatum (Pers) Rostaf (771A, 15; 777B, 7; 778B, 12; 810, 4; 817B, 6; 817G, 23; 826A, 3; 826E, 4; 830A, 2; 834, 2; 1051, 6; 1055, 3, 1059, 16; 1066, 53; 1089, 25).

Fuligo cf. *septica* (L.) F. H. Wigg (1010, 1) (0.9 x 1.5 mm).

Hemitrichia leiotricha (Lister) G. Lister (1005, 64).

Hemitrichia minor G. Lister (1006, 7; 1010, 1; 1011 cf, 7).

Lamproderma arcyrionema Rostaf. (1010, 7; 1068, 22).

Licea biforis Morgan (1011, 15; 1022, 15; 1024, 5; 1061, 16; 1065, 3; 1070, 25; 1071, 25; 1074, 20; 1080, 6).

Licea kleistobolus G. W. Martin (768B, 1000; 771, 4; 777B, 31; 1024, 1; 1032, 10; 1037, 2; 1038, 8; 1046, 2; 1055, 7; 1056, 1000; 1057, 9; 1058, 3; 1060, 20; 1061, 20; 1063, 30; 1064, 1; 1065, 7; 1068, 2; 1069, 1; 1070; 6; 1071, 2; 1072, 8; 1073, 22; 1074, 20; 1078, 20; 1085, 1; 1087, 103; 1089; 6).

Licea operculata (Wingate) G. W Martin (1006, 19; 1017 50; 1018, 4; 1033, 78; 1037, 77; 1042, 113; 1048, 42; 1060, 1; 1071, 1).

Licea pedicellata (H. C Gilbert) H. C Gilbert (858C, 8; 858F, 2; 1046, 200; 1061, 134; 1065, 48; 1075, 10; 1080, 4; 1085, 8).

Licea sp (sessile) (774, 10; 858C, 180; 858E, 10; 858H, 1; 1011, 30; 1019, 20; 1032, 4; 1034, 21; 1036, 2; 1037, 200; 1038, 160; 1044, 10; 1064, 39; 1065, 10; 1070, 1; 1075, 1000; 1089, 7)

Macbrideola argentea Nann, -Bremek & Y. Yamam (1057, 3).

Macbrideola decapillata H. C. Gilbert (770, 10; 845, 19; 858C, 50; 858D, 12; 858E, 14; 858F, 9; 1064, 10; 1019, 39; 1044, 21; 1046, 4; 1065, 25; 1072, 11; 1073, 3).

Macbrideola oblonga Pando, & Lado (770, 3; 809A, 5; 835, 12; 845, 4; 1011, 59; 1017, 22; 1022, 10; 1027, 5; 1032, 44; 1033,21; 1042, 4; 1044, 3; 1056, 7; 1058 cf, 3; 1070, 7; 1071, 10; 1072, 117; 1074, 31; 1080, 48).

Macbrideola scintillans H. C. Gilbert (1059, 16).

Macbrideola synsporos (Alexop) Alexop (1005, 1).

Oligonema? sp. A (1051, 19). See text for description.

Paradiacheopsis fimbriata (G. Lister & Cran) Hertel ex Nann –Bremek (817E, 1; 1032, 9; 1067, 3).

Paradiacheopsis microcarpa (Meyl) D. W Mitch ex Ing (769, 10; 810, 10; 817B, 20; 817F, 5; 817G, 9; 826B, 14; 1046 cf., 21).

Paradiacheopsis solitaria (Nann -Bremek) Nann –Bremek (809A, 20; 1013, 17; 1057, 1).

Perichaena depressa Lib (1010, 08; 1011, 2; 1020, 12; 1022, 19; 1036, 47; 1039, 2; 1046, 1; 1064, 27; 1068, 78; 1073, 18).

Perichaena vermicularis (Schwein) Rostaf (771, 14; 817D, 9; 830A, 8; 845, 4; 858B, 22; 858C, 13; 858F, 1; 858G, 35; 1010, 96; 1019, 13; 1022, 7; 1039, 207; 1046, 65; 1061, 108; 1063, 3; 1064, 170; 1068, 8; 1072, 10; 1073, 7; 1085, 26).

Physarum album (Bull) Chevall (858A, 35; 1048, 165).

Physarum cinereum (Batsch) Pers (1064, 54).

Physarum compressum Alb & Schwein (858C, 30)

Physarum crateriforme Petch (858C, 33).

Physarum decipiens M. A. Curtis (1011, 2; 1027, 17; 1028, 13; 1032, 31; 1033, 2; 1034, 19; 1036, 6; 1040, 30; 1049, 87; 1061, 4; 1063, 12; 1064, 2; 1068, 54; 1070, 17; 1072, 5; 1073, 42; 1081, 83).

Physarum flavicomum Berk (773, 30).

Physarum galbeum Wingate (1086, 100).

Physarum cf. hongkongense H. C. Chung (1010, 2).

Physarum leucophaeum Fr (1010, 38; 1011, 34; 1020, 103; 1039, 100; 1064, 13; 1065, 9; 1068, 2; 1070, 68; 1071, 75; 1073, 1; 1077, 219; 1088, 35).

Physarum notabile T. Macbr (1064, 11).

Physarum psittacinum Ditmar (1048, 7).

Physarum robustum (Lister) Nann –Bremek (1046, 24).

Physarum viride (Bull) Pers (817G, 27; 826B, 10)

Physarum various species (770, 2; 773, 8; 779A, 1; 817D, 6; 830B, 8; 845, 6; 858D, 3; 858F, 2; 1005, 6; 1007, 20; 1008, 5; 1024, 2; 1036, 13; 1040, 2; 1044, 10; 1049, 15; 1061, 3; 1064, 5; 1065, 150; 1068, 2).

Reticularia olivacea (Ehrenb) Fr (835, 3)

Stemonitis fusca Roth var. nigresscens Rex (774, 2; 809B, 1; 1068, 14; 1084, 27).

Stemonitis mussooriensis. G. W. Martin, K. S. Thind & Sohi (1017, 17; 1022, 3; 1057, 27; 1061, 30; 1084, 21; 1087, 10).

Stemonitopsis subcaespitosa (Peck) Nann –Bremek (1037, 5; 1040, 50).

Northern Territory and Queensland traverses

The distribution of the species is best visualized in a table of the species occurrences, with the samples shown in order along the traverse (NT, Table 2; Qld, Table 3). In these two tables all species are shown except those with fewer than three localities on the traverse. On both tables the species have been divided into three groups: species that occur the full length of both traverses, species that mainly occur on the wetter 2/3 to 3/4 of both traverses (Tropical Assemblage), and species that mainly occur on the dryer 2/3-3/4 of both traverses (Northern Dry Assemblage). The probable position of the zone boundaries is shown in the two tables. A difference between the two tables is that in Table 2 *Licea kleistobolus* is largely restricted to the Northern Dry assemblage, while in Table 3 it is also in the area of the Tropical Assemblage. This pattern of a Tropical and Northern Dry assemblage with a transition zone between them is not due to a change in the type of bark sampled along the traverses, because the same pattern is found for the traverses showing only soft barks, only hard barks, and for *Acacia* bark.

The transition zone has occurrences of both the Tropical and Northern Dry Assemblages. On the NT traverse this zone is about 370 km wide, and on the Queensland traverse about 280 km wide. On both traverses there is no decrease in frequency of occurrences of the Tropical Assemblage across the zone, or of the Northern Dry Assemblage across the zone. Hence in the transition zone there is a big increase in the average number of species in each sample. However that may not mean an increase in the total mass of myxomycete activity in the field.

Table 2. Species distribution along the Northern Territory traverse between Darwin and Alice Springs. A cross shows that the species is present in that sample. All species are shown except those with fewer than three localities on the traverse. The species have been divided into three groups: those present along the whole traverse, those mainly in the tropical region and transition zone, and those mainly in the transition zone and northern arid region.

sample number	54	55	1	2	52	51	48	49	5	6	7	8	45	46	10	11	13	44	15	16	17	18	19	20	22	24	27	28	30	42	31	32	33	34	35	36	37	38	39	40
latitude (°S)	13	13	13	13	13	14	14	14	14	14	14	14	14	14	15	15	15	15	15	15	16	16	16	16	18	18	19	20	20	21	21	21	22	22	22	22	22	23	23	24
	Tropical Assemblage												transition zone												Northern Dry Assemblage															
Arcyria cinerea	X						X		X		X			X			X				X	X	X		X		X				X					X				
Arcyria sp H						X											X																		X				X	
Comatricha elegans			X						X	X	X	X							X	X											X				X					
Comatricha ellae		X	X																X			X							X	X		X	X	X	X		X	X	X	X
Licea operculata							X			X											X	X								X			X				X			
Comatricha laxa																	X																				X?			
Cribraria confusa				X					X		X						X				X	X																		
Cribraria minutissima	X	X				X	X		X		X	X					X		X	X	X	X																		
Cribraria violacea								X						X	X	X							X	X																
Echinostelium minutum	X					X	X					X					X		X	X																				X
Enerthenema papillatum		X				X																																		
Hemitrichia minor										X					X	X																								
Badhamia affinis																				X			X		X		X													
Badhamia sp A														X													X													
Badhamiopsis ainoae													X			X																X		X						
Calomyxa metalica																X												X		X			X	X				X	X	X
Didymium dubium																		X									X											X		X
Licea biforis																X									X	X														
Licea kleistobolus														X												X						X					X	X		
Macbrideola decapillata														X				X					X																	
Macbrideola oblonga																X		X			X				X		X			X		X	X							
Perichaena depressa														X	X	X								X	X											X			X	
Perichaena vermicularis														X	X								X		X														X	
Physarum decipiens								X								X											X					X	X	X		X				X
Physarum leucophaeum															X	X								X															X	

Table 3. Species distribution along the Queensland traverse between Cairns and Winton. A cross shows that the species is present in that sample. All species are shown except those with fewer than three localities on the traverse. The species have been divided into three groups: those present along the whole traverse, those mainly in the tropical region and transition zone, and those mainly in the transition zone and northern arid region.

sample number	56	57	58	59	60	87	86	85	61	62	63	84	83	80	79	89	64	65	66	67	68	69	70	71	72	78	77	73	74	75	76
	Tropical assemblage								transition zone																	Northern dry assem.					
Arcyria cinerea		X		X						X		X	X		X		X				X				X	X		X			
Arcyria sp H		X			X	X										X															
Comatricha elegans	X	X	X	X					X	X	X		X		X	X			X	X		X			X		X				X
Comatricha ellae	X	X			X	X	X	X										X		X		X						X			
Licea operculata					X																		X								
Comatricha laxa	X	X																			X			X							
Cribraria confusa	X	X	X							X						X															
Cribraria minutissima	X	X	X	X	X	X	X			X	X		X			X				X		X									
Cribraria violacea								X	X			X					X								X						
Echinostelium minutum	X	X			X		X				X																				
Enerthenema papillatum				X												X			X												
Stemonitis mussooriensis		X					X		X			X																			
Badhamia sp A												X			X																X
Badhamiopsis ainoae									X					X			X														
Calomyxa metallica											X			X			X	X							X						
Didymium dubium											X			X								X								X	
Licea biforis									X					X				X					X	X					X		
Licea kleistobolus	X	X	X		X	X		X	X		X					X	X	X			X	X	X	X	X	X		X	X		
Licea pendicellata								X	X					X				X												X	
Licea pygmaea																															
Macbrideola decapillata																	X	X							X			X			
Macbrideola oblonga	X		X											X									X	X	X				X		
Perichaena depressa																	X				X							X			
Perichaena vermicularis									X		X						X				X				X			X			
Physrum decipiens									X		X						X				X		X		X			X			
Physarum leucophaeum																	X		X		X		X	X			X	X			

Table 4. Australian and overseas species assemblages. The columns show the various assemblages from Australia and overseas, both for the four Australian regions, and for individual surveys. Numbers refer to the number of sites. The common species in each assemblage are in bold. Numbers in brackets in the Southern Dry Assemblage indicate species that are thought to be part of the Temperate Assemblage. Origin of the data columns is as follows. Columns 1 and 2 from this paper. Column 3 from Wellman (2015). Column 4 addition of columns 7, 8, and 9. Column 5 from Novozhilov et al. (2003). Column 6 from Pando and Lado (1990) and Wrigley de Basanta (1998). Column 7 from Rosing et al. (2007). Column 8 from this paper. Column 9 from Mitchell (1992). Column 10 from Davison et al. (2008). In columns 5 and 6 data is only given for the species found in Australia and New Zealand.

	1	2	3	4	5	6	7	8	9	10
area	NT+Qld	NT+Qld	NW NSW	Aus,NZ	Colorado	Spain	Vict	SE NSW	NZ	Simp
climate	tropical	N arid	S arid	temp	arid	arid + temp	temp	temp	temp	arid
av rainfall (mm)	600 - 1500	300 - 600	200 - 400	600- 1600	130-250	400-1000	600- 1500	600-1100	600- 1600	210
latitude (deg)	13-21	14-24	29-33	33-44	35-38	36-44	36-38	33-36	36-44	23-24
Arcyria cinerea	**18**	**18**	**5**	**13**	1	**4**	3	8	2	1
Arcyria sp H	**6**	**4**	**8**	1				1		1
Arcyria pomiformis				**8**			3	2	3	
Badhamia affinis		4		1	1	**2**		1		
Badhamia sp A	**4**	**5**								
Badhamia macrocarpa			(4)	2	3	**3**	1	1		
Badhamiopsis ainoae		**7**	**6**	1	**5**	**3**		1		
Calomyxa metalica		**13**	**12**	**18**	**10**		1	11	6	
Clastoderma debaryanum				2		1	2			
Comatricha anomala			3	1				1		
Comatricha elegans	**14**	**7**		**7**		1	3	3	1	6
Comatricha ellae	**10**	**13**	**18**	9		**2**		9		
Comatricha laxa	5	1	2	4	**25**	**4**	2	1	1	9
Comatricha pulchella			2							
Cribraria confusa	**11**		(1)	**13**			4	9		
Cribraria minutissima	**25**	1	(1)	**8**			3	5		
Cribraria violacea	**11**			**5**	1	**2**	1	4		
Dianema corticatum			**13**	1	2				1	
Didymium clavus			(2)							
Didymium decipiens cf			**5**							
Didymium dubium		**8**	**10**	4	**10**		4			1
Didymium squamulosum				2	1	**4**		2		1
Echinostelium minutum	**12**			**25**	**8**	**7**	8	12	5	
Enerthenema papillatum	**5**		**5**	**17**	**27**	**5**	3	10	4	
Hemitrichia minor	3				1					
Licea biforis		**9**	**10**	4	**8**	1	1		3	4
Licea kleistobolus	6	**18**	**15**	5	**70**	**5**	1	3	1	6
Macbrideola decapilata		**7**		**12**	2	1		6	6	
Macbrideola oblonga	2	**13**	**17**	4	**12**	**5**		4		3
Macbrideola synsporos				2	1	**4**	1		1	
Paradiacheopsis fimbriata			3	**9**	1	**2**	1	1	7	1
Paradiacheopsis microcarpa			(6)	7				6	1	
Perichaena depressa		**10**			2					
Perichaena vermicularis		**11**	**15**	**9**	**50**	**4**	1	8		1
Physarum decipiens	1	**14**	**21**		**70**	**7**				3
Physarum leucophaeum		**11**	3	2	**22**	**2**			2	
Physarum robustum			**12**	1				1		
Physarum viride				**4**				3	1	
Reticularia olivacea			3	1				1		
Stemonitis fusca				2		2		2		
Stemonitis mussooriensis	**4**			1					1	
Stemonitopsis amoena			**2**							
Trichia contorta			(3)		**3**	**6**				
records in table	119	156	190	205	336	77	43	116	46	37

Southeast New South Wales area, and a composite temperate species assemblage

The species identified in this area are given in Table 1, with sample number 768 to 858. The sample sites range from 33.28 to 35.85°S and 148.27 to 151.13°E, and from 23 to 1421 m altitude. The annual rainfall of the sites ranges from 600 to 1100 mm, with the higher rainfall both along the coastline and on the relatively high land inland, and lower rainfalls on the 600-800 m altitude tableland inland and at lower altitudes to the west. The average rainfall is distributed fairly uniformly through the year. The various areas collected seem to have a similar species assemblage, with no major changes in assemblage associated with change in rainfall, altitude, or distance inland.

This SE NSW data set is relatively small, so a larger, composite data set for temperate climate areas was constructed using, in addition, two previously reported corticolous myxomycete surveys. Rosing et al. (2007) report a survey in eastern Victoria (Fig. 1) of 24 samples from 12 localities (36.07-37.70°S 145.33-149.35°E) with a range in average rainfall from 600 to 1500 mm/yr. Mitchell (1992) reported results of his New Zealand work, for samples collected from Auckland to Otago Provinces. These samples are in the area 36-44°S 169-176°E, that has a mean annual rainfall between 600 and 1600 mm/yr. The results reported in SW of Western Australia have not been used because of the small number of records, and the uncertainty in the position of the transition zone at the margin of the temperate species assemblage. The three surveys used gave similar results, and generally the same dominant species. An exception is the absence of *Cribraria minutissima* and *C. confusa* in New Zealand. This absence may be due to New Zealand having fewer low density barks optimized for fire resistance. Table 4 shows the significant species and their abundances for these three temperate surveys, and the calculated composite Temperate Assemblage.

Results from a previously published northwest New South Wales survey

A survey of corticolous myxomycetes across NW NSW is described by Wellman (2015). To ensure that the data sets are compatible between surveys some identifications have been checked. The reported *Comatricha ellae* have been looked at again, and I do not believe that they are *C. elegans or C. laxa*. *Paradiacheopsis rigida* and *Macbrideola synsporos* (Alexop.) are now not thought to be present. *Paradiacheopsis microcarpa* is at sites 862C, 864B, 866A, 878B, 880A, 882A, and *Macbrideola cf. ovoidea* Nann. –Bremek. & Y. Yaman at sites 870A, 878A and 883A.

This survey was carried out as a traverse in the shape of a square (Fig. 1), where the eastern side of the square approximately follows the 400 mm mean annual rainfall contour. Most of the species found in NW NSW are found fairly uniformly along the whole traverse, these species are the Southern Dry Assemblage. A few species are found only at a few sites on the eastern margin of the survey: *Badhamia macrocarpa, B. versicolor, Clastoderma pachypus, Cribraria confusa, C. minutissima, Didymium clavus, Macbrideola argentea, Paradiacheopsis microcarpa,* and *Trichia contorta.* These are interpreted to belong to the Temperate Assemblage to the east. In this interpretation the eastern margin of this survey is just within the transition zone between the Southern Dry and Temperate assemblages.

Discussion

Comparison of corticolous myxomycete assemblages

Table 3 summarizes the four distinct assemblages found in the above surveys, named here; Tropical, Northern Dry, Southern Dry, and Temperate. The species listed in Table 3 comprise all the species in the surveys discussed above for Australia and New Zealand, with the exception of Oligonema ? sp. A. In this table some numbers are in 'bold'; they are entries where the species frequency of occurrence is much higher relative to one or more of the other assemblages. Species common in the Northern and Southern Dry Assemblages include *Badhamia sp A, Badhamiopsis ainoae, Calomyxa metallica, Comatricha ellae, Dianema corticatum, Didymium dubium, Licea biforis, Licea kleistobolus, Macbrideola obonga, Perichaena depressa, Physarum decipiens, P. leucophaeum*, and *P. robustum*. Many of these species have previously been identified as characteristic of arid climates. The two dry assemblages differ in a few species that occur abundantly: *Badhamia sp A, B. affinis, and Macbrideola decapillata* in the Northern Dry Assemblage, and *Dianema corticatum, Didymium decipiens, Enerthenema papillatum* and *Physarum robustum,* in the Southern Dry Assemblage. Species common in the wetter areas (Tropical and Temperate Assemblages) include *Arcyria pomiformis, Comatricha elegans, C. laxa, Cribraria confusa, C. minutissima, C. violacea, Echinostelium minutum*, and *Stemonitis mussooriensis*.

The difference between these four assemblages is difficult to quantify exactly because it should take into account the effect of randomness of the species occurrence, and the observed frequency of occurrence. Rather roughly taking these factors into account the apparent species turnover-over across the boundary between the tropical to northern dry assemblages is 80% on both the Northern Territory survey (Table 2) and the Queensland survey (Table 3), is about 50% between the northern dry and southern dry assemblages (Table 4), and about 40% between the southern dry and temperate assemblages (Table 4).

In Table 4 the number of records may seem small, but this is a bit misleading. For example *Macbrideola oblonga* was found in 13 samples in the Northern Dry Assemblage area, out of a total of 51 samples. Approximately one half of the trees had suitable old dead bark at 1.5 m above ground level. The samples are random for these surveys, so this species is probably found 1.5 m above ground in 12% of all trees along the surveys. Similar climates occur over about one quarter of Australia, so if one considers the occurrences for the whole tree, then this species is likely to occur in more than 12% of all trees in this large area of about 3000 km by 700 km.

A range of survey layouts has been used above to investigate the continent-wide corticolous myxomycete distribution. The most successful layout is a fairly straight traverse over 1000 km long, from the highest to lowest rainfall, across a region of low rainfall gradient.

Comparison between the myxomycete regions and Australian phytogeographic regions

Gonzalez-Orozco et al. (2014) use vascular and non-vascular plant records for Australia to look at the rate of change of species composition across Australia. They use this information to divide Australia into phytogeographic regions (PR), and subregions. Figure 2 shows the main phytogeographic regions, with superimposed information on the locations of the four myxomycete assemblages. It is clear from the figure that there is a good correspondence between the extent of the Tropical, Northern Dry, Southern Dry, and Temperate myxomycete assemblages where known, with the boundaries of the Northern, Northern Desert, Eremaean and Eurontotian PR.

The climatic and main phytogeographic regions of Australia are east-west trending bands over the western two thirds of Australia, but in the eastern third of Australia they follow the shape of the eastern margin (Fig. 2). The boundary between the Northern/Northern Desert PR follows the 650 mm mean annual rainfall. The boundary between the Eremaean PR and the eastern part of the Euronotian PR boundary follows the 500 mm mean annual rainfall, while to the west the southern boundary of the Eremaean PR follows the 250 mm mean annual rainfall. The position of the Northern Desert/ Eremaean PR boundary does not reflect a change in mean annual rainfall. It probably reflects the southwards decrease in winter temperatures and summer rainfall, and southwards increase in winter rainfall.

The boundaries of the myxomycete assemblages correspond where known with both the phytogeographic regions and climate regions, so it is likely that the myxomycete assemblages have the same geographic extent as the phytogeographic and climatic regions. Figure 3 shows the inferred areal extent of the myxomycete assemblages. The inferred assemblages extent have a simple form of bands oriented east-west except in the east. This distribution along a climatic zone is what would be expected for myxomycetes (and other cryptogams) as they grow from airborne spores which travel widely, so they should occur throughout a climatic zone. Australian evidence for a wide distribution of cryptogams along a climatic zone is based on data in the temperate climatic zone, as this is the best studied. Myxomycetes, collected by field collection from wood and bark substrates, have one species assemblage across temperate southern Australia (Wellman, in prep). Mosses and liverworts also have similar species assemblages across temperate southern Australia, when you compare comparable ecological sites, as shown by the occurrences in Meagher & Fuhrer (2003).

The map of phytogeographic regions and subregions (González-Orozco et al. 2014), is quite complicated with many east/west subdivisions of the east-west climatic zones. These complications are not climatic. It is likely that they reflect the past distribution of flowering plant species, so they are not relevant to cryptogams.

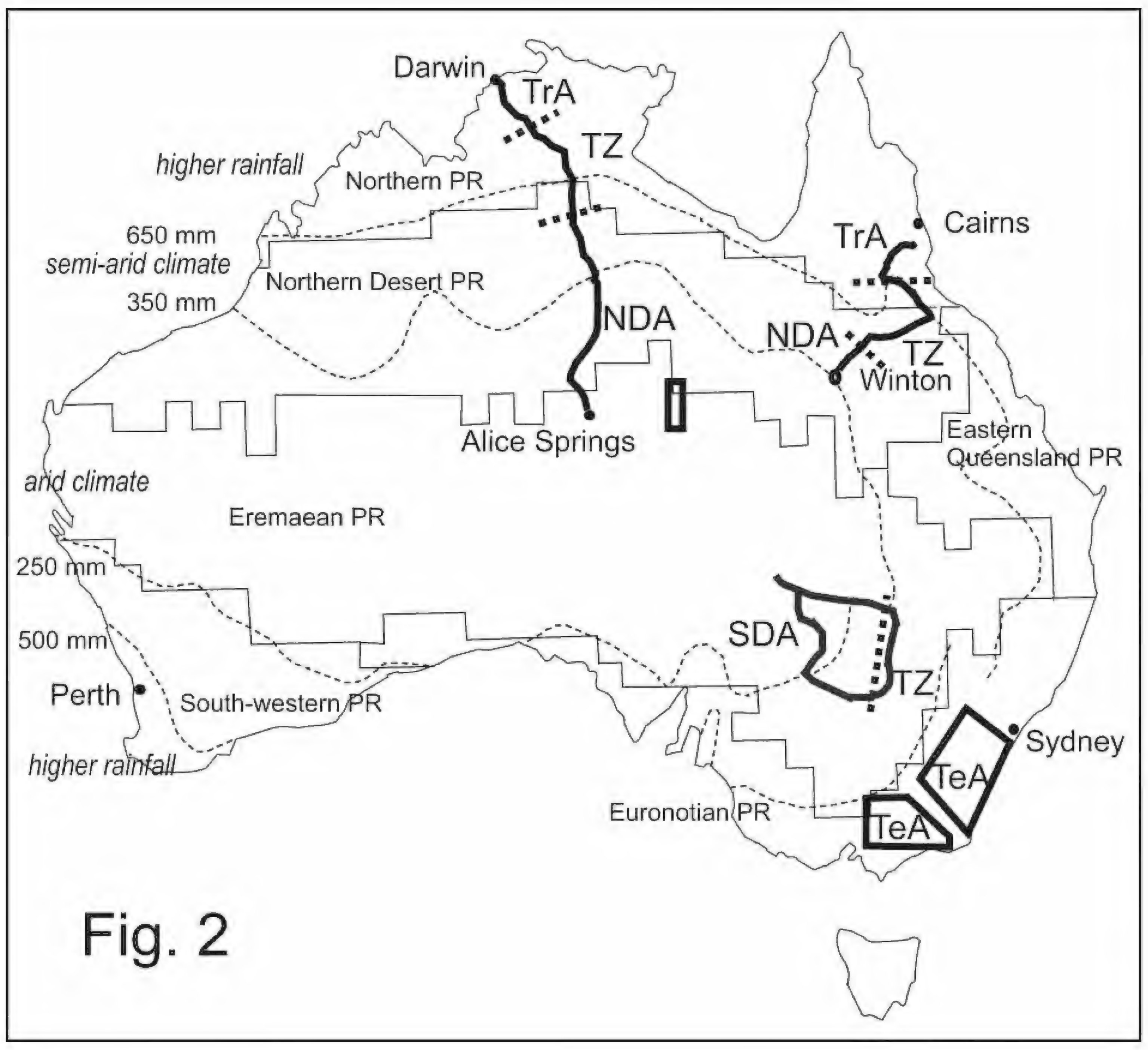

Fig. 2. Relationship between the myxomycete assemblage areas, climatic regions and phytogeographic regions (PR). Note that the boundary between the Tropical and Northern Dry Assemblages is over the outer boundary of both the semi-arid climate and the Northern Desert PR, and the boundary between the Southern Arid and Temperate assemblages is over the outer boundary of both the semi-arid climate, and the Eremaean PR. The boundary of the transition zone between myxomycete regions is shown by cross lines. NDA, Northern Dry Assemblage; SDA, Southern Dry Assemblage; TeA, Temperate Assemblage, TrA, Tropical Assemblage, TZ, transition zone.

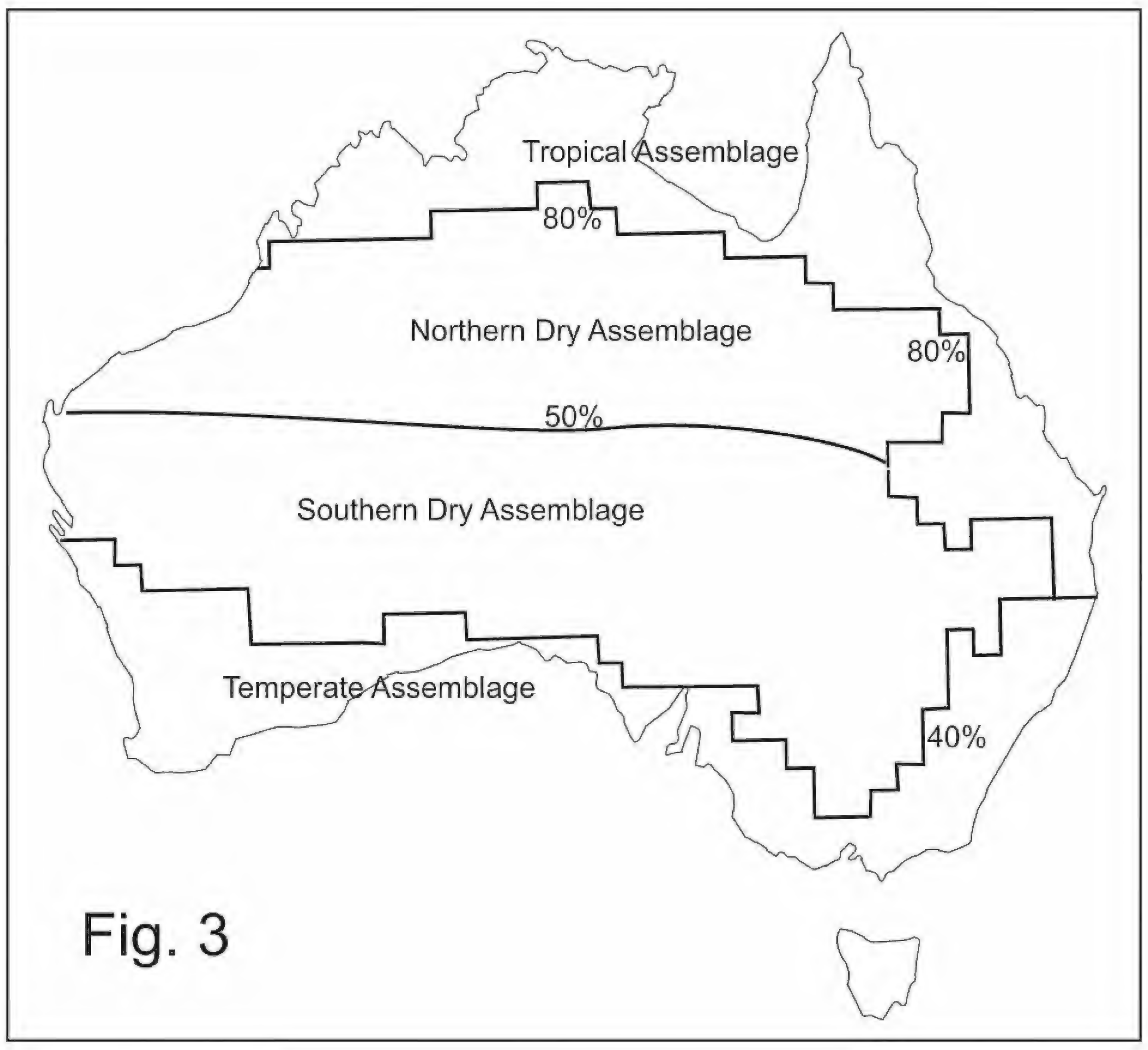

Fig. 3. Map of the likely distribution of corticolous myxomycete assemblages in Australia. The percentages give the observed species turnover at the assemblage boundary.

Transition zones

Of some interest is what controls the width of the transition zones. The transition between the Tropical and Northern dry assemblages is shown above to have a width of 370 km in NT, and 280 km in Qld. The width of the transition between the Northern and Southern dry assemblages is unknown, in part because the Simpson Desert survey of Davison et al. (2008) (given in Table 4) did not obtain a long enough species list to determine the myxomycete assemblage. The width must be less than the distance between the NT survey and the NW NSW survey of 600 km. The transition between the Southern Dry and Temperate Assemblages extends into the NW NSW survey 50-100 km, but does not reach the SE NSW survey 300 km distant. So its width is less than 400 km, and is likely to be about 300 km. Hence the best estimate of the mean width of the transition zones is between 300 and 400 km. The changes in mean annual rainfall across these transition zones are 600 mm for the Tropical to Northern Dry transition zone in NT, and 200 mm in Qld. Between the Northern and Southern Arid assemblages the change is 100 mm, and from the Southern Arid to the Temperate the change is 250 mm. As the transition zone width is more consistent than the change in mean annual rainfall, width is the most likely controlling factor.

If there are four myxomycete corticolous assemblages in Australia, and the transition zones are 200-300 km wide then transition zones would cover about 30% of Australia. An interesting comparison is with the larger World biogeographical regions. On the basis of the map of Morrone (2015) the ratio of the area of transition zone to regions is more like 20%, but the value is uncertain because his map is not an equal area projection. However there is an important difference between the two types of region apart from scale. The myxomycetes regions are a response to climatic differences, as all species are available to grow because of widespread spores, while the world biogeographical regions are the result of past evolution and the barriers to migration, not a response to climate. There is no information in Gonzalez-Orozco et al. (2014) as to the width of the transition zones of the phytogeographic regions.

Similarity of Australian and overseas species assemblages

Although there are many papers on corticolous myxomycetes surveys outside Australia, only a few deal with areas between the equator and 40° latitude, and with tree bark rather than cactus or succulent substrate.

A high-quality survey is reported by Novozhilov et al (2003) for the Colorado Plateau, in southwestern United States. The area was 35-38°N, 106-112°W, 1200-3000 m altitude, and annual precipitation of 130-250 mm, with a higher rainfall in summer. Table 4 tabulates the results for these bark samples, leaving out species not found in Australia and New Zealand. Ignoring *Echinostelium* and *Licea*, and species occurring mainly on sage bush (a substrate type that does not occur in Australia), only 15% of the Colorado records are not on Table 4, and of those species not listed only three species formed more than 1% of the records: *Didymium difforme* with 13 records, *Physarum notabile* with 9 records, *Protophysarum phloioenum* with 10 records. This Colorado Plateau assemblage is remarkably similar to that of the Southern Arid Assemblage in Australia. An important difference is that in the Colorado Plateau assemblage the common *Comatricha* is *C. laxa,* and in the Southern Arid Assemblage it is *C. ellae.*

A species assemblage can be composed for corticolous myxomycetes in the Iberian Peninsula (continental Spain and Portugal). This area is latitude 36-44°N. The peninsular has high annual rainfall on the narrow area along its northern and northwest margins, with most of the remaining area having 400-700 mm over the coast and plateau plains, and 700-1000 mm over the higher ground of the plateau. This plateau has a low summer rainfall. A composite species assemblage was constructed by giving unit weight to each province listed in Pando and Lado (1990) (excluding the Balearic Islands), and giving unit weight to each locality in Wrigley de Basanta (1998). The resultant species assemblage is given in Table 4, again leaving out species not found in the Australian and New Zealand assemblages. As expected from the rainfall range and latitude, it is similar to a combination of the Temperate and Southern Arid Assemblages in Australia, but with the greatest affinity to the Southern Arid Assemblage. The Spanish assemblage may be a mixture of two discrete assemblages with a minimal transition zone, or it may lie within a wide transition zone.

The Colorado Plateau and the Iberian Peninsula have similar climate to the southern arid and temperate regions in Australia, and they give species assemblages. This is consistent with myxomycete assemblages around the world being similar in regions of similar climate.

Conclusions

Results from the surveys of corticolous myxomycetes indicate that the species assemblages do not show a gradual change across Australia. Rather, there are large discrete areas with a single species assemblage, and these areas are separated by transition zones containing both assemblages. Species turnover at the boundaries is 50-80%. The species assemblages are best characterized by the dominant species, and their relative abundance. The pattern of species assemblages is consistent with boundaries mapped for both the climatic subdivisions of Australia and with the main Australian phytogeographic regions. The three myxomycete assemblage boundaries that were found correspond with the boundary between the tropical and arid areas, the southern boundary of effective monsoon rainfall, and between arid and temperate areas.

There are few well-reported myxomycete surveys at similar latitudes and climate in the Northern Hemisphere. However, the species assemblage in the Colorado plateau of USA is similar to that of NW NSW, and the assemblage of the Iberian Peninsula in Europe is similar a combination of NW and SE NSW assemblages. This is consistent with similar myxomycete species assemblages occurring around the world in areas of similar climate, including latitude.

Acknowledgements

I wish to thank the Australian National Herbarium for the use of laboratory facilities. I received great help and encouragement from Christine Cargill, Judith Curnow and Heino Lepp of the Cryptogam Herbarium at the Australian National Herbarium, Catherine Jordan of the Australian National Botanic Gardens library, Steve Stephenson of University of Arkansas, and (during field work) from Mike Morriss of Canberra. The collections will be deposited in the Australian National Herbarium (CANB).

References

Black, D.R., Stephenson, S.L. & Pearce, C.A. (2004). Myxomycetes associated with the aerial litter microhabitat in tropical forests of northern Queensland, Australia. *Systematics and geography of plants* 74: 129-132.

Davison, E.M., Davison, P.J.N. & Brims, M.H. (2008). Moist chamber and field collections of myxomycetes from the northern Simpson Desert, Australia. *Australasian Mycologist* 27: 129-135.

Davison, E.M., Davison, P.J.N., Barrett, M.D., Barrett, R.L., McMullan-Fisher, S.J.M. (in press). Additions to the myxomycota of summer rainfall regions of tropical Australia. *Nova Hedwigia*.

Discover Life (2015). Discoverlife website, <http://discoverlife.org>, accessed 2016.

González-Orozco C.E., Ebach M.C., Laffan S., Thornhill A.H., Knerr N.J., Schmidt-Lebuhn A.N., et al. (2014) Quantifying Phytogeographical Regions of Australia Using Geospatial Turnover in Species Composition. PLoS ONE 9(3): e92558. doi:10.1371/journal.pone.0092558

Ing, B. (1999). *The myxomycetes of Britain and Ireland*. The Richmond Publishing Co. Ltd, Slough.

Ing, B. & Spooner, B.M., (1994). Myxomycetes from the Kimberley Region, Western Australia. *Botanical Journal of the Linnean Society* 116: 71-76.

Jordan, C.C., Brims, M.H., Speijers, E.J.; Davison, E.M., (2006). Myxomycetes on the bark of *Banksia attenuata* and *B. menziesii* (Proteaceae). *Australian Journal of Botany* 54: 357–65.

Knight, K.J. & Brims, M.H. (2010) Myxomycota census of Western Australia. *Nuytsia* 20: 283-307.

Lloyd, S. (2014). *Where the slime mould creeps, the fascinating world of myxomycetes*. Tympanocryptis Press, Pirralee, Tasmania.

Martin, G.W. & Alexopoulos, C.J. (1969). *The myxomycetes*. University of Iowa Press, Iowa City.

McHugh, R., Stephenson, S.L., Mitchell, D.W. & Brims, M.H. (2003). New records of Australian myxomycota. *New Zealand Journal of Botany* 41: 487-500.

McHugh, R., Mitchell, D.W., Brims, M.H., & Stephenson, S.L. (2009). New additions to the myxomycota of Australia. *Australasian Mycologist* 28: 56-64.

Meagher, D, & Fuhrer, B. (2003). A field guide to the mosses and allied plans of Southern Australia. *Flora of Australia supplementary series 20*.

Mitchell, D.W. (1992). The myxomycota of New Zealand and its island territories. *Nova Hedwigia* 55: 231-256.

Mitchell, D.W. (1995). The myxomycota of Australia. *Nova Hedwigia* 60: 269-295.

Morrone, J.J. (2015). Biogeographical regionalisation of the world: a reappraisal. *Australian Systematic Botany* 28: 81-90.

Nannenga-Bremekamp, N.E. (1991). *A guide to temperate myxomycetes*. Biopress Limited, Bristol.

Novozhilov, Y.K., Mitchel, D.W., & Schnittler, M. (2003). *Myxomycete biodiversity of the Colorado Plateau*. Mycological Progress 2: 243-258.

Pando, F. and Lado, C. (1990). A survey of the corticolous myxomycetes in peninsular Spain and Balearic Islands. *Nova Hedwigia*, 50: 127-137.

Poulain, M., Meyer, M. & Bozonnet, J. (2011). *Les myxomycètes. Fédération mycologique et botanique Dauphiné-Savoie*, Sevrier, 2 volumes.

Rosing, W.C., Mitchell, D.W. & Stephenson, S.L. (2007). Corticolous myxomycetes from Victoria. *Australasian Mycologist* 26: 9-15.

Stephenson, S.L. (2003). Myxomycetes of New Zealand. *Fungi of New Zealand*, Volume 3. Fungal Diversity Research Series 11, Fungal Diversity Press, Hong Kong.

Stephenson, S.L. & Shadwick, J.D.L. (2009). Nivicolous myxomycetes from alpine areas of south-eastern Australia. *Australian Journal of Botany* 57: 116-122.

Stephenson, S.L. & Stempen, H. (1994). *Myxomycetes, a handbook of slime moulds*. Timber Press, Portland, Oregon.

Wellman, P. (2015). Myxomycetes (slime moulds) of arid and semi-arid areas of northwest New South Wales, Australia. *Cunninghamia*, 15: 153-162.

Wrigley de Basanta, D. (1998). Myxomycetes from the bark of the evergreen oak *Quercus ilex*. *Anales del Jardín Botánico de Madrid* 56: 3-14.

Wrigley de Basanta, D., Stephenson, S.L., Lado, C., Estrada-Torres, A, & Nieves-Rivera, A.M. (2008). Lianas as a microhabitat for myxomycetes in tropical forests. *Fungal Diversity* 28: 109-125.

Manuscript accepted October 2016

Appendix 1. List of the samples of the Northern Territory and Queensland traverses, giving the position and the tree name.

sample	tree name and town	latitude	longitude	altitude
		°S	°E	m
	Darwin	12.46	130.82	15
1001	*Eucalyptus miniata*	12.70	131.09	66
1002	*Eucalyptus tetrodonta*	12.70	131.09	66
1005	*Erythrophleum*	13.78	131.85	207
1006	*Acacia*	13.78	131.85	207
1007	*Eucalyptus tetrodonta*	13.78	131.85	207
1008	unknown	13.78	131.85	207
1010	*Eucalyptus,* box bark	14.56	132.46	170
1011	*Acacia*	14.56	132.46	170
1013	*Erythrophleum*	14.56	132.46	170
1015	*Eucalyptus,* box	15.32	133.15	184
1016	*Eucalyptus*	15.32	133.15	184
1017	*Erythrophleum*	16.20	133.43	202
1018	*Erythrophleum*	16.20	133.43	202
1019	*Lysiphyllum*	16.20	133.43	202
1020	unknown	16.20	133.43	202
1022	*Corymbia*	17.86	133.69	244
1024	unknown	18.34	133.81	269
1027	*Eucalyptus gamophylla*	19.22	134.17	311
	Tennant Creek	19.64	134.20	376
1028	*Acacia*	19.86	134.20	335
1030	*Hakea*	19.86	134.20	335
1031	*Corymbia*	21.35	134.01	451
1032	*Acacia*	21.50	133.91	503
1033	*Acacia*	21.73	133.74	486
1034	*Grevillea*	21.73	133.74	486
1035	*Corymbia*	21.73	133.74	486
1036	*Eucalyptus coolabah*	21.78	133.68	485
1037	*Hakea*	21.78	133.68	485
1038	*Acacia*	23.16	133.73	702
1039	*Eucalyptus intertexa*	23.36	133.80	717
1040	*Hakea*	23.60	133.88	672
	Alice Springs	23.70	133.87	568
1042	*Acacia aneura*	21.29	134.05	443
	Tennant Creek	19.64	134.20	376
1044	*Terminalia*	14.97	133.00	141
1045	*Fiscus opposita*	14.37	132.17	136
1046	*Eucalyptus tetrodonta*	14.37	132.17	136
1048	*Erythrophleum*	13.71	131.70	220
1049	*Terminalia*	13.71	131.70	220
1051	*Eucalyptus polycarpa*	13.52	131.27	137
1052	*Corymbia phychocarpa*	13.35	131.13	82
1054	*Eucalyptus tetrodonta*	12.58	131.31	25
1055	unknown	12.58	131.31	25
	Darwin	12.46	130.82	15

sample	tree name and town	latitude	longitude	altitude
		°S	°E	m
	Cairns	16.93	145.78	3
1056	*Eucalyptus crebra*	17.79	144.96	721
1057	*Callitris glaucophylla*	17.79	144.96	721
1058	*Corymbia dolichocarpa*	17.79	144.96	721
1059	*Eucalyptus,* stringybark	17.79	144.96	721
1060	*Acacia*	17.79	144.96	721
1061	*Eucalyptus,* box	19.09	145.19	455
1062	*Corymbia dolichocarpa*	19.09	145.19	455
1063	*Casuarina cunninghamiana*	19.09	145.19	455
	Charters Towers	20.07	146.27	290
1089	*Corymbia dolichocarpa*	20.25	145.81	354
1064	*Eucalyptus,* box	20.25	145.81	354
1065	*Lysiphyllum*	20.25	145.81	354
1066	*Grevillia*	20.25	145.81	354
1067	*Corymbia*	20.73	145.20	534
1068	unknown	20.73	145.20	534
1069	*Grevillia*	20.73	145.20	534
1070	*Acacia cambagei*	21.04	144.04	284
1071	*Lysiphyllum*	21.04	144.04	284
1072	*Eucalyptus coolabah*	21.06	144.02	270
1073	*Eucalyptus coolabah*	22.42	143.03	180
1074	*Lysiphyllum*	22.42	143.03	180
1075	*Acacia*	22.42	143.03	180
1076	*Eremophila bignoniiflora*	22.42	143.03	180
	Winton	22.39	143.04	192
1077	*Atalaya hemiglauca*	21.75	143.35	263
1078	*Tamerix articulata*	21.64	143.44	238
	Charters Towers	20.07	146.27	290
1079	*Eucalyptus cambageana*	19.86	146.13	264
1080	*Owenia acidula*	19.86	146.13	264
1081	*Casuarina cunninghamiana*	19.86	146.13	264
1082	*Eucalyptus tereticornis*	19.86	146.13	264
1083	*Corymbia dolichocarpa*	19.49	145.72	351
1084	*Eucalytus tessellaris*	19.47	145.71	341
1085	*Eucalyptus,* box	18.94	144.63	564
1086	*Grevillia*	18.87	144.55	604
1087	*Erythrophleum*	18.87	144.55	604
	Cairns	16.93	145.78	3

Appendix 2. List of the samples of the SE New South Wales survey, giving their position and the tree name.

Brindabella Mountains
Latitude 35.37 - 35.42°S, Longitude 148.80 - 148.83°E, Altitude 886 - 1263 m

768B	*Eucalyptus fastigata*
769	*Exocarpus cupressiformis*
817B	*Pirea rubens*
817C	*Pseudotsgy menziesii*
817D	*Cupressus arizonica*
817E	*Pinus couteri*
817F	*Chamaecyparis lawsoniana*
817G	*Larix leptolepis*

Canberra
35.23 - 35.38°S, 148.95 - 149.11°E, 453 - 772m

770	*Casuarina cunninghamiana*
771	*Eucalyptus melliodora*
772A	*Exocarpus cupressiformis*
772C	*Eucalyptus macrorhyncha*
773	*Eucalyptus sideroxylon*
774	*Eucalyptus* 'box bark'
775B	*Casuarina cunninghamiana*
841	*Pistacia vera*
844	unknown tree
845	*Platanus*

Tumut
35.37 - 35.42°S, 148.27 - 148.29°E, 417 - 447 m.

777B	*Eucalyptus macrorhyncha*
778B	*Eucalyptus radiata*
779A	*Quercus*

Monga National Park
35.61- 35.97°S, 149.87 - 149.90°E, 944 -948 m.

809A	*Eucalyptus* 'ash'
809B	*Eucalyptus* 'pepermint type'
810	*Eucalyptus macrorhyncha*

Wollongong
34.08 - 34.40°S, 150.86 - 151.13°E, 23 - 327 m.

826A	*Syncarpia glomulifera*
826B	unknown tree
826E	*Eucalyptus* 'layered bark'
827A	*Allocasuarina torulosa*
828A	unknown tree
887	*Persoonia linearis*?

Goulburn
34.73°S, 149.83°E, 644 m.

830A	*Populus nigra* 'Italica'
830B	*Quercus pyrenaica*

Adaminaby
35.85°S, 148.85°E, 1351-1421 m.

834	*Eucalyptus dalrympleana*
835	*Eucalyptus radiata*

Orange
33.28°S, 149.08°E, 920 m.

858A	*Cedrus atlantica*
858B	*Cupressus lawsonia*
858C	*Ulmus procera*
858D	*Photinia fraseri* "Robusta"
858E	*Aesculus hippocastanum*
858F	*Magnolia grandiflora*
858G	*Sequoiadendrian giganteum*
858H	*Platanus acerifolia*